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**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-134

October 1982

# Managing Intermountain Rangelands —Sagebrush-Grass Ranges

James P. Blaisdell
Robert B. Murray
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## PREFACE

Sagebrush-grass rangelands have been the subject of considerable research during the past half century. The resulting literature is extensive. Harniss and others (1981) have published a bibliography with 1,250 citations. Tisdale and Hironaka (1981) have authored a review of ecological literature on sagebrush-grass.

Most managers and users of rangelands have neither ready access to the literature nor the time necessary to search it.

This current publication is not a comprehensive review of the literature. It is a distillation of some of the most important information that may be helpful in planning and decisionmaking. Our purpose is to provide sagebrush-grass rangeland managers and users with a reference or guide to research results. Those wanting more detailed information can follow up on the literature citations here or in the aforementioned bibliography or review of ecological literature.

Some of the more recent research has shown that sagebrush-grass ecology is more varied and complex than we once thought. Therefore, we have devoted considerable space to taxonomy and classification of sagebrush ecosystems. These sections can be useful working materials for resource managers.

Partly because of the ecological variation within the broad sagebrush-grass rangeland area, and partly because past research has been concentrated more in some parts of the West than in others, it is not possible to apply all research results to all sagebrush-grass lands. Good judgment and understanding the several sagebrush ecosystems are necessary in extending the results of any research findings.

We hope that managers and users of western rangelands find this to be a useful reference.

## RESEARCH SUMMARY

Sagebrush-grass vegetation makes up one of the largest range ecosystems in the Western United States. Much of it was abused during early settlement of the West, and much of it is still far below its potential in livestock forage production, wildlife habitat, and environmental quality. Sagebrush-grass rangelands have been the subject of considerable research during the past half century. The resulting literature is extensive—with over 1,250 citations. Most managers and users of rangelands cannot study and digest all this material for themselves. This paper is a distillation of some of the most important information available that may be helpful in planning and decisionmaking. It is intended to be a manager's reference and guide to research results. It includes summaries of the latest information on sagebrush taxonomy and classification of sagebrush ecosystems as well as on methods of rehabilitating, converting, and managing these ecosystems.

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## THE AUTHORS

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## INTRODUCTION

### The Resource

Sagebrush includes the species, all woody, of subgenus *Tridentatae* of the genus *Artemisia*. Sagebrush-grass vegetation occupies a substantial portion of the western range. It extends over much of Utah, Nevada, southern Idaho, eastern Oregon, western Montana, Wyoming, and Colorado, as well as smaller areas in Washington, California, Arizona, and New Mexico (Tisdale and others 1969). Estimates of total acreage vary from some 95 million acres (38 million ha) (USDA Forest Service 1936 and 1972) to 270 million acres (109 million ha) (Beetle 1960). Even if the lower estimate is accepted as reasonably accurate, sagebrush-grass vegetation is still one of the largest—if not the largest—range ecosystem in the western United States.

Native sagebrush-grass vegetation is dominated by woody species of *Artemisia* with an understory of perennial grasses and forbs. However, vegetal cover is usually not continuous and considerable bare ground is often exposed. Sagebrush generally occurs at elevations from 5,000 to 7,000 ft (1 525 to 2 140 m), but some species grow at elevations as low as 1,600 ft (490 m) and others as high as 11,500 ft (3 500 m). Dwarf sagebrushes are mostly confined to the shallow soils, whereas the tall sagebrushes generally occur on the deeper soils and comprise the greatest area. Other important shrubs are rabbitbrush (*Chrysothamnus*), bitterbrush (*Purshia*), horsebrush (*Tetradymia*), chokecherry (*Prunus*), serviceberry (*Amelanchier*), hopsage (*Grayia*), Mormon tea (*Ephedra*), wild currant (*Ribes*), mountain mahogany (*Cercocarpus*), and snowberry (*Symphoricarpos*).

Although a large number of herbaceous species are present throughout the sagebrush ecosystem, a relatively few species comprise the bulk of the biomass. Principal grasses are wheatgrasses (*Agropyron*), fescues (*Festuca*), bluegrasses (*Poa*), bromegrasses (*Bromus*), junegrass (*Koeleria*), needlegrasses (*Stipa*), squirreltail (*Sitanion*), ricegrass (*Oryzopsis*), and wildrye (*Elymus*). Forbs are present in a much greater variety than grasses, but their distribution is much less uniform. However, one species, arrowleaf balsamroot (*Balsamorhiza sagittata*), is very widespread and often abundant. Other common forbs present in varying quantities are yarrow (*Achillea*), pussytoes (*Antennaria*), locoweed (*Astragalus*), segolily (*Calochortus*), hawksbeard (*Crepis*), larkspur (*Delphinium*), daisy (*Erigeron*), buckwheat (*Eriogonum*), biscuitroot (*Lomatium*), lupines (*Lupinus*), foxglove (*Penstemon*), phlox (*Phlox*), groundsels (*Senecio*), violet (*Viola*), mulesears (*Wyethia*), and deathcamas (*Zigadenus*) (Blaisdell 1958; Cronquist and others 1972). These forbs are highly variable in characteristics, ranging from matformers such as *Phlox hoodii* and *Antennaria* to tall, coarse plants such as *Balsamorhiza* and *Lupinus leucophyllus*. Root systems vary from stout, deep taproots in the latter two species to spreading, rhizomatous systems in others.

The sagebrush-grass ecosystem is inhabited by a wide variety of mammals and birds. Antelope, mule deer, elk, sage grouse, mourning doves, and chukar partridges are the most important game species. The Utah prairie dog is an endangered species of this ecosystem. Other occupants are coyotes, jackrabbits, pygmy and cottontail rabbits, ground squirrels, and kangaroo rats. More than 50 species of birds are commonly found including golden and bald eagles; marsh, red-tailed, Swainson's, and Cooper's hawks; prairie falcons; and long-eared and burrowing owls (Garrison and others 1977).

Because of easy accessibility, high productive potential, and its size, sagebrush-grass range constitutes an important resource for production of livestock and wildlife, watershed values, and a wide variety of recreational activities. It is also a resource reserve to be improved and maintained as an important national asset available to satisfy presently unforeseeable needs (Blaisdell and others 1970).



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## Problems

Unfortunately, much of the valuable sagebrush resource was depleted during the early years of western settlement by abusive grazing, by unregulated and recurrent fires, and by cultivation and abandonment of marginal lands. Despite several decades of "improved" management, the sagebrush ecosystem is still far below its potential in livestock forage production, wildlife habitat, and environmental quality (USDA Forest Service 1972).

A primary problem is the increase in numbers and size of sagebrush and other low value shrubs that have accompanied the reduction in perennial grasses and forbs. Not only is this a direct loss of forage, but resulting stands of sagebrush are frequently so dense that they form a barrier to livestock movements. Sheep can make their way through such stands only with difficulty, wool is pulled from fleeces, and lambs are lost through straying. Even when livestock force their way into thick sagebrush stands, they are often unable to reach more than half of the palatable grasses and forbs. Because of its long life and ability to compete with perennial herbs for soil moisture and nutrients, sagebrush in dense stands is a serious obstacle to range improvement through grazing management or seeding of desirable species (Blaisdell 1953).

In other extensive areas, destruction of sagebrush-grass vegetation by fire, heavy grazing, or cultivation has allowed conversion to annuals, particularly cheatgrass (*Bromus tectorum*). Although ranges dominated by this exotic may provide good spring forage, it is not dependable because of wide year-to-year fluctuations in yield. Also, cheatgrass is a serious fire hazard and allows invasion of poisonous or other weeds such as halogeton (*Halogeton glomeratus*), Russian thistle (*Salsola kali*), tumble mustard (*Sisymbrium altissimum*), medusahead (*Taeniatherum asperum*), bur buttercup (*Ranunculus testiculatus*), sunflower (*Helianthus annuus*), tarweed (*Madia*), prickly lettuce (*Lactuca serriola*), and stickseed (*Lappula occidentalis*).

Although accelerated erosion has often accompanied vegetal deterioration, severe runoff and erosion has not occurred on many areas now occupied by thick stands of sagebrush and annuals. However, serious problems have been created by flooding, especially in parts of the Great Basin where deep channels have been cut in many small streams. Often aquatic habitat has been seriously damaged, and the normal riparian vegetation has been modified or destroyed as a result of a lowered water table and heavy grazing pressure. Secondary consequences of range deterioration, then, are lowered grazing capacity for livestock, reduction in populations of fish and wildlife, and damage to environmental quality, especially esthetics.

Obviously, the solution is restoration of desirable vegetation through direct improvement and/or grazing management practices. The task will not be easy. Advanced deterioration of vegetation and soil will be difficult to correct, and variability of the ecosystem will complicate the development of workable prescriptions. Sagebrush-grass range, which was once thought to be fairly uniform, is now known to contain numerous subunits of vegetation determined by differences in climate, soil, and topography. These communities are characterized by specific kinds of sagebrush (species, subspecies, varieties, ecotypes, forms, strains, and so forth) in combination with complex mixtures of other shrubs, grasses, and forbs. Sagebrush can be valuable or pestiferous in different degrees depending on inherent qualities or location; consequently, sagebrush systematics must be addressed to identify taxa that require peculiar management strategies (McArthur 1979). Likewise, sound classification of natural landscape units based on potential and on an understanding of ecosystem dynamics is needed to facilitate management decisions for sagebrush-grass ranges (Tisdale and others 1969). Knowledge of range condition or relative health of the vegetation and soil and whether it is getting better or worse (trend) is essential for planning livestock grazing programs or managing other land uses (Pechanec and Stewart 1949).

# TAXONOMY OF SAGEBRUSH

## Classification

The North American sagebrushes comprise subgenus *Tridentatae* (Rydb.) E. D. McArthur of the genus *Artemisia* L. Although its taxonomic limits remain in some dispute, *Tridentatae* is a natural grouping of species based on habit, morphology, anatomy, chemistry, and cytology (McArthur 1979; McArthur and others 1981). Incidentally, it seems reasonable to follow McArthur's suggestion of using "sagebrush" when referring to the *Tridentatae* group of *Artemisia* and "sage" for the non-*Tridentatae*.

In 1814, Pursh described the first *Tridentatae* species, *A. cana* Pursh, from material collected in 1804 by explorers Lewis and Clark. Nuttall described two widespread species, *A. tridentata* Nutt. and *A. arbuscula* Nutt., in the early 1840's. Rydberg (1916) developed a systematic treatment of *Artemisia*, and his framework has been used by subsequent workers, especially Hall and Clements (1923), Ward (1953), Beetle (1960), and Beetle and Young (1965). The relations between the various species and subspecific taxa are shown in table 1.

An additional taxon, *A. tridentata* ssp. *vaseyana* form "*xericensis*," was suggested by Winward (1970). However, he more recently proposed that this variant (tentatively referred to as type "X") be given higher status as a subspecies of *A. tridentata* (Winward 1975). Although critical evaluation of sagebrush taxonomy should continue, it appears that Beetle's system is generally adequate for classification of most sagebrush entities.

**Table 1.**—Development of subgenus *Tridentatae*[1] of genus *Artemisia* (from McArthur 1979)

| Beetle (1960) Beetle and Young (1965) | Ward (1953) | Hall and Clements (1923) | Rydberg (1916) |
|---|---|---|---|
| *A. arbuscula* Nutt. ssp. *arbuscula* | *A. arbuscula* ssp. *arbuscula* | *A. tridentata* ssp. *arbuscula* (Nutt.) H&C | *A. arbuscula* |
| *A. arbuscula Nutt.* ssp. *thermopola* Beetle | — | — | — |
| *A. argillosa* Beetle | — | — | — |
| *A. cana* Pursh ssp. *cana* | *A. cana* ssp. *cana* | *A. cana* | *A. cana* |
| *A. cana* Pursh ssp. *bolanderi* (Gray) Ward | *A. cana* ssp. *bolanderi* | *A. tridentata* ssp. *bolanderi* (Gray) H&C | *A. bolanderi* Gray |
| *A. cana* Pursh ssp. *viscidula* (Osterhout) Beetle | *A. cana* ssp. *cana* | *A. cana* | *A. cana* |
| *A. longiloba* (Osterhout) Beetle | *A. spiciformis* var. *longiloba* Osterhout | — | — |
| *A. nova* Nelson | *A. arbuscula* ssp. *nova* (Nelson) Ward | *A. tridentata* ssp. *nova* (Nelson) H&C | *A. nova* |
| *A. rothrockii* Gray | *A. rothrockii* | *A. tridentata* ssp. *rothrockii* (Gray) H&C | *A. rothrockii* |
| *A. tridentata* Nutt. ssp. *tridentata* | *A. tridentata* ssp. *tridentata* | *A. tridentata* ssp. *typica* | *A. tridentata* |
| *A. tridentata* Nutt. ssp. tridentata | *A. tridentata* ssp. *tridentata* | *A. tridentata* ssp. *typica* | *A. angusta* Rydb. |
| A. tridentata Nutt. ssp. *tridentata* f. *parishii* (Gray) Beetle | *A. tridentata* ssp. *parishii* (Gray) H&C | *A. tridentata* ssp. *parishii* | *A. parishii* Gray |
| *A. tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle | *A. tridentata* ssp. *tridentata* | *A. tridentata* ssp. *rothrockii* (Gray) H&C | *A. vaseyana* Rydb. |
| *A. tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle f. *spiciformis* (Osterhout) Beetle | — | *A. tridentata* ssp. *rothrockii* (Gray) H&C | *A. spiciformis* Osterhout |
| *A. tridentata* Nutt. ssp. *wyoming-ensis* Beetle and Young | — | — | — |
| *A. tripartita* Rydb. *tripartita* | *A. tripartita* | *A. tridentata* ssp. *trifidia* (Nutt.) H&C | *A. tripartita* |
| *A. tripartita* Rydb. ssp. *rupicola* Beetle | — | — | — |
| | | | TRIDENTATAE[2] |
| *A. pygmaea* Gray | *A. pygmaea* | *A. pygmaea* | *A. pygmaea* PYGMAEAE |
| *A. rigida* (Nutt.) Gray | *A. rigida* | *A. rigida* | *A. rigida* RIGIDAE |
| *A. bigelovii* Gray | *A. bigelovii* | *A. bigelovii* | *A. bigelovii* ABROTANUM |

[1]Rydberg (1916) and Beetle (1960) used subgenus Tridentatae whereas Hall and Clements (1923) and Ward (1953) referred to North American members of the subgenus Seriphidium.
[2]Some of Beetle's (1960) Tridentatae species were assigned to other sections by earlier workers.

## Identification

Fairly complete keys to the taxa of *Tridentatae* were prepared by Beetle (1960) and McArthur and others (1979). Also, useful keys to the *Artemisia tridentata* complex in Idaho and in Oregon were developed by Winward and Tisdale (1977) and Winward (1980), respectively. Because it is the most recent and comprehensive, the McArthur and others key is reproduced here in figure 1; however, the other three are also useful and are included in the appendix.

Based on their own research, as well as a thorough review of the literature, McArthur and others (1979) have developed descriptions of the most important sagebrush taxa. Summaries, emphasizing characteristics and distribution, follow in alphabetical order.

### *ARTEMISIA ARBUSCULA* NUTT. (LOW SAGEBRUSH)

Low sagebrush is a spreading, irregularly branched shrub up to 20 inches (5 dm) high. The slender erect twigs are densely canescent, but may become nearly glabrous and thus darker green in late summer. The plant layers infrequently. Leaves are broadly cuneate or fan-shaped, 0.2 to 0.6 inch (0.5 to 1.5 cm) long and 0.1 to 0.4 inch (0.3 to 1 cm) wide, and usually have three (occasionally four to five) teeth or clefts at the apex. Leaves on the upper part of the flowering shoots may become entire. Flower heads are grouped into elongated, narrow racemes. The heads usually contain 5 to 11 disc flowers with corollas 0.12 to 0.16 inch (3 to 4 mm) long. The 10 to 15 involucral bracts are canescent. Flowering occurs from August to September, depending upon strain and elevation. Seed ripens in October and November.

1a Heads with both ray (marginal) flowers and disc flowers; plants subshrubs or shrubs.

2a. Plants subshrubs; leaves 2 or 3 times pinnately parted, silky-canescent; widely distributed through western North America, Siberia, northern Asia, and Europe ............................... *A. frigida* (fringed sagebrush)

2b. Plants shrubs; leaves not as above.

3a. Branches spinescent, leaves 3 to 5 palmately parted with segments three-lobed, white tomentose, deciduous; occurs on dry, saline plains and hills from northwestern Montana west to eastern Oregon and south to California, Arizona, and New Mexico .............. *A spinescens* (bud sagebrush)

3b Branches not spinescent; leaves not as above.

4a. Leaves filiform, entire or ternately divided into filiform segments, silvery-white canescent; heads with 2 to 3 ray flowers and 1 to 6 disc flowers; occurs mostly in sandy soil from Nevada east to western Nebraska and south to Texas, Arizona, and Chihuahua ........................................ *A. filifolia* (sand sagebrush)

4b. Leaves narrowly cuneate, mostly finely tridentate, silvery-canescent; heads smaller with 0 to 2 ray flowers and 1 to 3 disc flowers; occurs in canyons, gravelly draws, and dry flats from western Texas to California ........................................ *A. bigelovii* (Bigelow sagebrush)

1b Heads with disc flowers only, plants shrubs.

5a Plants up to 5 dm high.

6a. Plants dwarf, less than 2 dm high.

7a. Plants depressed, cushionlike shrubs; leaves 2 to 8 mm long, pinnately divided into 3 to 11 lobes; limited to calcareous desert soils, central and western Utah, central and eastern Nevada, and northern Arizona ........................................ *A. pygmaea* (pigmy sagebrush)

7b. Plants with decumbent, frequently layering branches; leaves often 3 cm long, deeply cleft into 3 linear lobes; rocky knolls from 2 430 to 2 740 m in central and southeastern Wyoming to southern Oregon ................................ *A tripartita* ssp. *rupicola* (Wyoming threetip sagebrush)

6b Plants low from 2 to 5 dm high (but may be less).

8a. Heads axillary and sessile, generally all surpassed by their subtending leaves; leaves deeply divided into 3 to 5 narrowly linear lobes; deciduous .................... *A. rigida* (stiff sagebrush)

8b. Heads usually in branched racemose panicles or if spikelike, then subtending leaves do not surpass heads; leaves three- to five-toothed or lobed, cuneate to fan-shaped, persistent.

9a. Leaves broadly cuneate, deeply three-lobed involucre broadly companulate; flower heads 3 to 5 mm broad with 6 to 11 disc flowers; blooming begins in mid-June; seeds 2.5 mm long, ripening in August, adapted to heavy, highly impermeable, saline soils from 1 800 to 2 450 m from southwestern Montana to northwestern Colorado, Utah, Nevada, Idaho, and Oregon ....................... *A. longiloba* (alkali sagebrush)

9b. Leaves cuneate to broadly cuneate or fan-shaped, three- to five-toothed or cleft; involucre narrowly campanulate; flower heads and seed smaller than above; blooming normally occurring later than July; seed ripen late September and October.

10a. Leaves cuneate, three-toothed (upper leaves may be entire), viscid; heads arranged in narrow spikelike panicles; disc flowers 3 to 5 per head; corollas 1.8 to 3 mm long; involucral bracts glabrous or nearly so; plants usually dark green with persistent red-brown inflorescent stalks; occurs on dry, shallow, rocky soil between 1 500 and 2 400 m in most western States ........................................ *A. nova* (black sagebrush)

10b. Leaves broadly cuneate or fan-shaped, three- to five-toothed or cleft (upper leaves may be entire), not viscid; heads arranged in narrow racemose panicles; disc flowers 5 to 11 per head; corollas 3 to 4 mm long; involucral bracts canescent; plant usually lighter in color than above; distribution similar to *A nova* but offset to the northwest, usually found at somewhat higher elevations in more moist habitats than *A. nova* ........ *A. arbuscula* (low sagebrush)

**Figure 1.--Key to species and subspecies of *Artemisia* (from McArthur and others 1979).**

5b. Plants usually over 5 dm high (14b and 17b provide most exceptions to 5 dm height).

11a. Leaves silvery-canescent, linear to linear-oblanceolate, mostly entire (occasionally with a few irregular teeth), or leaves deeply divided into 3 or more linear or linear-oblanceolate lobes

12a. Leaves entire or occasionally with 1 or 2 irregular teeth or lobes . . . . . . . *A. cana* (silver sagebrush)

13a. Leaves 2 to 8 cm long, 1 to 10 mm wide, densely silky-canescent, heads arranged into dense leafy panicles, occurs mostly east of the Continental Divide from southern Canada to northern Colorado . . . . . *A. cana* ssp. *cana* (silver sagebrush)

13b. Leaves smaller than above (up to 7 cm long, 1 to 5 mm wide) and often crowded into dark-green clusters; heads arranged into dense, short raceme or spikelike inflorescences; occurs mostly west of the Continental Divide from southwestern corner of Montana to Arizona and New Mexico . . . . . . *A. cana* ssp. *viscidula* (mountain silver sagebrush)

12b. Leaves typically deeply divided into 3 linear or narrowly lanceolate lobes which in turn may be three-cleft . . . . . . . . . . *A. tripartita* (threetip sagebrush)

14a. Plants freely branching shrubs up to 2 m; leaves 1.5 to 4 cm long, deeply divided into 3 linear lobes, each less than 1 mm wide; occurs on dry, well-drained soils from 900 to 1 800 m from British Columbia south to northern Nevada, northern Utah and western Montana . . . . . . . . . . . . . . *A. tripartita* ssp. *tripartita* (tall threetip sagebrush)

14b. Plants dwarf shrubs with decumbent, often layering branches, leaves up to 3 cm long, deeply divided into linear lobes 1 mm or more wide; occurs on rocky knolls from 2 430 to 2 740 m in central and southeastern Wyoming to southern Oregon . . . . . . . . . . . . . . . . . . . . . *A. tripartita* ssp. *rupicola* (Wyoming threetip sagebrush)

11b. Leaves not silvery-canescent, narrowly lanceolate to broadly cuneate or fan-shaped, typically three-toothed or lobed (upper leaves may be entire).

15a. Plants low-growing, flat-topped shrubs up to 8 dm high, leaves somewhat viscid; heads occurring singly or occasionally up to 3 arranged in short interrupted spike or racemelike inflorescences; heads large with up to 20 disc flowers each; occurs in high mountainous areas of central Colorado, western Wyoming, Utah, central Sierras of California, and Carson Range of Nevada . . . . . . . . . . . . . . . . *A. rothrockii* (timberline sagebrush)

15b. Plants ranging from dwarf to tall, arborescent forms up to 4.5 m; leaves not viscid, inflorescences of numerous heads arranged into leafy panicles, heads smaller with 3 to 8 disc flowers; most widespread and common shrub of western North America . . . . . . . . . . . . . . . . . . . . *A. tridentata* (big sagebrush)

16a. Plants uneven-topped shrubs with flowering stalks arising throughout the crown, leaves narrowly lanceolate to cuneate; odor of crushed leaves pungent.

17a. Mature plants often arborescent (with single trunklike main stem), usually from 1 to 2 m but in some forms up to 4.5 high; leaves narrowly lanceolate with margins not curving outward; average persistent 5.6 times its width; blooming starts in late August or September, odor strongly pungent, normally occurs below 2 100 m in dry deep, well-drained soils on plains, valleys, and foothills . . . . . . . *A. tridentata* ssp. *tridentata* (basin big sagebrush)

17b. Mature plants with several main branches usually less than 1 m high, leaves narrowly cuneate to cuneate with margins curved outward, average persistent leaf length is 3.1 times its width, blooming starts in late July or August, odor pungent, occurs on dry, shallow, gravelly soil from 1 500 to 2 100 m . *A. tridentata* ssp. *wyomingensis* (Wyoming big sagebrush)

16b. Plants usually even-topped shrubs with flower stalks arising from upper crown portions; leaves broadly cuneate to spatulate; average persistent leaf length is 4.0 times its width; blooming may begin in July, odor slightly pungent to pleasantly mintlike, occurs from 1 400 to 3 000 m in deep well-drained soils . . . . . . . . . . . . . . . . . . *A. tridentata* ssp. *vaseyana* (mountain big sagebrush)

A dwarf form of *A. arbuscula* occurs in the Stanley Basin area of Idaho, the Jackson Hole, Wyo., area, and perhaps in other locations. Beetle (1960) named this form *A. arbuscula* ssp. *thermopola*—hotsprings sagebrush. He speculated that this form arose as the result of hybridization between typical *A. arbuscula* and *A. tripartita*.

Low sagebrush grows on dry, sterile, rocky, often alkaline soils between 2,300 and 11,500 ft (700 and 3 500 m) covering approximately 39,100 mi$^2$ (10.1 million ha) in 11 western States. In the warmer, drier parts of its range, particularly in Nevada, it may grow well into the mountains above 9,800 ft (3 000 m). In some areas, low sagebrush occurs on disjunct low and high elevation bands.

Low sagebrush ranges from southern Colorado to western Montana and west throughout Utah and Idaho to northern California, Oregon, and Washington. Normally its sites are more rocky than those with big sagebrush, and are wetter in the spring and drier in the fall.

Low sagebrush and black sagebrush sometimes occur in intermixed stands. In areas where the distribution of these two species overlaps, low sagebrush is usually found in the more moist habitats or at slightly higher elevations than black sagebrush.

### *ARTEMISIA ARGILLOSA* BEETLE (COALTOWN SAGEBRUSH)

Coaltown sagebrush is an erect shrub 20 to 32 inches (5 to 8 dm) tall. Leaves are up to 1.6 inches (4 cm) long, deeply trifid, resembling those of *A. tripartita*, but commonly longer with wider lobes. Flower heads appear in July, bloom in August, and seed ripens by October. This species has a limited distribution of about 1 mi$^2$ (260 ha) in Jackson County, Colo., where it occurs on strongly alkaline soil (Beetle 1960). It is, however, abundant on this site where it is associated with Wyoming big sagebrush and alkali sagebrush.

### *ARTEMISIA BIGELOVII* GRAY (BIGELOW SAGEBRUSH)

Bigelow sagebrush is a low shrub 8 to 16 inches (2 to 4 dm) high with numerous spreading branches. The flowering stems are slender and erect and bear inflorescences that are long, narrow panicles with short, recurved branches. New growth is covered with a silvery-canescent pubescence. The leaves of vegetative branches are similar to those of big sagebrush. They are narrowly cuneate, 0.4 to 0.8 inch (1 to 2 cm) long, 0.08 to 0.2 inch (2 to 5 mm) wide, and normally tridentate, but may have extra tips. The odor of crushed leaves is mild like that of mountain big sagebrush (*A. tridentata* ssp. *vaseyana*). The heads are arranged into elongated, narrow panicles and normally contain 1, but occasionally 0 to 2, ray flowers and 1 to 3, usually 2, disc flowers. The turbinate involucre consists of 8 to 12 short, densely tomentose bracts 0.08 to 0.16 inch (2 to 4 mm) long and 0.06 to 0.1 inch (1.5 to 2.5 mm) broad. Flowering occurs from August to October.

Bigelow sagebrush closely resembles and is often mistaken for low forms of big sagebrush produced by overgrazing and burning. In contrast to big sagebrush, however, it has ray flowers. Furthermore, lobes of *A. bigelovii*'s vegetative leaves are always more shallow and more sharply dentate than those of big sagebrush.

Bigelow sagebrush has a more southerly distribution than other sagebrushes, and is one of the most drought-resistant. It occurs over approximately 34,000 mi$^2$ (8.8 million ha) through western Texas, southern Colorado, New Mexico, Arizona, Utah, Nevada, and California in canyons, gravelly draws, and dry flats from 3,000 to 7,900 ft (900 to 2 400 m).

### *ARTEMISIA CANA* PURSH (SILVER SAGEBRUSH)

Silver sagebrush is an erect, freely branched, rounded shrub up to 5 ft (1.5 m) tall. Older branches have dark brown, fibrous bark while younger branches are covered with a dense white to yellowish-green tomentum. Leaves on the vegetative branches are 0.04 to 0.4 inch (1 to 10 mm) wide and 0.8 to 3.2 inches (2 to 8 cm) long, linear to linear-oblanceolate, entire or occasionally with 1 or 2 ephemeral leaves with irregular teeth or lobes, silver-canescent becoming slightly viscid with age. Leaves on the flowering stems are similar, but they may be slightly smaller, especially on the upper parts of the stems. The foliage emits a mild to pungent aromatic odor when crushed. Numerous heads are arranged into dense, narrow, leafy panicles, sometimes reduced to raceme or spikelike inflorescence. Each head contains 4 to 20 disc flowers. Ray flowers are lacking. Achenes are granuliferous. Blooming occurs during August and September.

Silver sagebrush occurs over approximately 53,200 mi$^2$ (13.8 million ha) from British Columbia to Saskatchewan, south to Nebraska, Colorado, and New Mexico, and west to Oregon and California on valleys, plains, foothills, and mountains up to 10,000 ft (3 050 m).

*Artemisia cana* ssp. *cana* (silver sagebrush) is an erect, rounded, freely branched shrub up to 5 ft (1.5 m) tall. It layers whenever conditions are suitable. This subspecies may spread rapidly, particularly after burning, by rootsprouting and by rhizomes. Leaves of the vegetative branches are linear-oblanceolate, entire or rarely with one or two irregular teeth or lobes, 0.04 to 0.4 inch (1 to 10 mm) wide, 0.8 to 3.2 inches (2 to 8 cm) long, and are densely silky-canescent. Crushed foliage emits a pungent turpentine odor. Flower heads are usually arranged into dense, leafy panicles and may contain from 5 to 20 disc flowers. Blooming occurs during September, and the seeds ripen during October and November. It occurs from southern Canada southward, but mostly east of the Continental Divide, through Montana, the Dakotas, Wyoming, western Nebraska, and northern Colorado.

*Artemisia cana* ssp. *viscidula* (mountain silver sagebrush) is an erect shrub that readily layers. It usually is not more than 3.3 ft (1 m) tall. Leaves on the vegetative branches are 0.04 to 0.2 inch (1 to 5 mm) wide, up to 2.8 inches (7 cm) long, and are often crowded in dark green clusters. The leaves typically are simple and entire, but occasionally ephemeral leaves are variously toothed or lobed. This subspecies varies in appearance, but is always darker green than mountain big sagebrush with which it is often growing. Mountain silver sagebrush is distinguished from subspecies *cana* by its smaller, darker green leaves, its lower stature, and more western distribution. Flower heads are arranged into dense, short raceme or spikelike inflorescences 0.4 to 1.2 inches (1 to 3 cm) long. Each head contains from 4 to 15 disc flowers. Flowers bloom during August and September. Seed matures during October and November. Mountain silver sagebrush occurs in mountainous regions around 6,900 ft (2 100 m) and above. It is usually found along streamsides and in areas of heavy, lingering snowpack from the southwest corner of Montana, south along the Continental Divide to New Mexico, and west to Arizona, Nevada, Utah, and Idaho.

*Artemisia cana* ssp. *bolanderi* (Bolander silver sagebrush) is a subspecies that occurs in extreme western Nevada and in

California and Oregon. It is similar to but more canescent than ssp. *viscidula* and grows on internally drained, usually more alkaline soils than *viscidula*.

### *ARTEMISIA LONGILOBA* (OSTERHOUT) BEETLE (ALKALI SAGEBRUSH)

Alkali sagebrush is a low shrub up to 18 inches (4.5 dm) tall. It has lax, spreading stems that frequently layer. The bark is dark brown to black on the older stems. The whole plant has a dark gray-green appearance. Leaves on the vegetative stems are broadly cuneate, up to 0.8 inch (2 cm) long, and are deeply three-lobed. Leaves of the flowering stems are similar but smaller on the upper part of the plants. Crushed foliage emits a pungent odor similar to that of camphor in the spring, and to hydraulic fluid in the fall.

Alkali sagebrush is readily distinguished from other low sagebrushes by its large heads and early blooming period. Its heads contain 6 to 11 disc flowers and are 0.12 to 0.2 inch (3 to 5 mm) broad as opposed to 0.12 inch (3 mm) or less for other low species. Alkali sagebrush blooms approximately a month earlier than other low sagebrushes. It flowers during mid-June to mid-July and its seed ripens in late July or early August. This species has sometimes been confused with *A. cana* because of its large heads, with *A. tridentata* because of its broadly cuneate, three-lobed leaves, and with *A. arbuscula* because of its dwarf size.

Unlike other sagebrushes, alkali sagebrush characteristically grows in heavy, highly impermeable soils derived from shales, but it also is frequently found on the lighter, limey soils. It occurs between 5,900 and 8,000 ft (1 800 and 2 450 m) in elevation over 5,120 $mi^2$ (1.3 million ha) along the foothills of the ranges forming the Continental Divide from southwestern Montana, south through Wyoming to northwestern Colorado, and scattered westward to Utah, Nevada, Idaho, and Oregon.

### *ARTEMISIA NOVA* NELSON (BLACK SAGEBRUSH)

Black sagebrush is a small, spreading, aromatic shrub 6 to 18 inches (1.5 to 4.5 dm) tall with a dull grayish-tomentose vestiture that causes most populations to appear darker than big sagebrush and low sagebrush. However, some forms might be as light in color as *A. tridentata* or *A. arbuscula*. Numerous erect branches arise from a spreading base, but this shrub has not been observed to layer or stump sprout. Typical leaves are evergreen, cuneate, viscid from a glandular pubescence, 0.2 to 0.8 inch (0.5 to 2 cm) long, 0.08 to 0.32 inch (2 to 8 mm) wide, and three-toothed at the apex. The uppermost leaves, particularly on the flowering stems, may be entire. Flower heads are grouped into tall, narrow panicles that extend above the herbage. The inflorescence stalks are red-brown and persistent. The heads usually contain from three to five disc flowers with corollas 0.07 to 0.12 inch (1.8 to 3 mm) long. The 8 to 12 involucral bracts are greenish-yellow and nearly glabrous. Flowering occurs from August to mid-September, and seeds mature in October and November.

The principal difference between black sagebrush and low sagebrush is that the latter has 5 to 11 flowers per head, 10 to 15 canescent involucral bracts, and is light in color. Black sagebrush has fewer flowers per head (3 to 5), 8 to 12 glabrous involucral bracts, and is usually darker in color. Also, the flower stalks of black sagebrush are denser, much darker, and more persistent than those of low sagebrush.

Black sagebrush covers approximately 43,300 $mi^2$ (11.2 million ha) in the 11 western States. It is most abundant at elevations from 5,000 to 8,000 ft (1 500 to 2 400 m) and normally grows on drier, shallower stony soil than basin or mountain big sagebrush. It has an affinity for calcareous soils.

### *ARTEMISIA PYGMAEA* GRAY (PIGMY SAGEBRUSH)

Pigmy sagebrush is a dwarf, depressed, evergreen, cushionlike shrub less than 8 inches (2 dm) tall. Bark on older stems becomes dark brown and fibrous. On young branches, the bark is nearly white to straw-colored and somewhat puberulent. Leaves on the vegetative stems are green, nearly glabrous, 0.08 to 0.16 inch (2 to 4 mm) wide, 0.08 to 0.32 inch (2 to 8 mm) long, and are pinnatified with 3 to 11 lobes, or sometimes may be only toothed. Leaves on the flowering branches are usually reduced and may be entire. Heads with three to five disc flowers are arranged into spikelike inflorescence. Ray flowers are lacking. Twelve to eighteen greenish-yellow bracts subtend each head. Achenes are glabrous. Flowers bloom in August and September, and seed matures in October. Seeds are large for *Artemisia*.

Pigmy sagebrush is limited to calcareous soils in desert areas over approximately 20 $mi^2$ (5 000 ha) from eastern Utah to western Nevada, and northern Arizona. In Nevada, this species is often associated with the halophytic *Chrysothamnus nauseosus* ssp. *consimilis*. Some fairly large stands occur with black sagebrush in Utah.

### *ARTEMISIA RIGIDA* (NUTT.) GRAY (STIFF OR SCABLAND SAGEBRUSH)

Stiff sagebrush is a low, pungently aromatic shrub with thick, rigid, somewhat brittle branches up to 16 inches (4 dm) high. It is not known to rootsprout or layer. The deciduous, silvery-canescent, spatulate leave are mostly 0.4 to 1.6 inches (1 to 4 cm) long and deeply divided into three to five narrowly linear lobes. Occasionally some leaves are linear and entire. Inflorescence is a leafy spike with heads sessile or in small clusters in the axils of their subtending leaves, which generally are all longer than the heads. The campanulate involucre is 0.16 to 0.20 inch (4 to 5 mm) long with numerous, canescent bracts. Each head consists of 5 to 16 perfect disc flowers. Flowering occurs during September and October; seeds ripen in November.

Stiff sagebrush occurs in dry rocky scablands in the Columbia and Snake River basins and spills over into the northern end of the Great Basin. It grows at elevations from 3,000 to 5,000 ft (900 to 1 500 m) in Idaho, central and eastern Oregon, and central and eastern Washington. It is adapted to the rocky scablands of these States and fills an ecological niche similar to that of *A. arbuscula* in the areas where it is found.

### *ARTEMISIA ROTHROCKII* GRAY (TIMBERLINE SAGEBRUSH)

Timberline sagebrush is a consistently low-growing, evergreen, flat-topped shrub from 4 to 32 inches (1 to 8 dm) tall. Its appearance in the field closely resembles some forms of mountain big sagebrush. Timberline sagebrush, however, has a more pronounced, consistent tendency to layer and has thicker, darker, more or less viscid leaves, which give the plant a dark green color. Leaves on the vegetative branches are often 0.4 inch (10 mm) broad and 1.2 inches (3 cm) long but range in size from 0.08 to 2 inches (2 to 51 mm) wide and 0.2 to 2 inches (0.5 to 5 cm) long. The lower leaves are mostly broadly cuneate or fan-shaped and three-toothed or lobed. The upper leaves, however, may be entire and linear to lanceolate or oblanceolate. The foliage is mildly aromatic when crushed.

Flower heads occur singly or occasionally one to three, in short interrupted spike or racemelike inflorescences. Each head contains 6 to 16, rarely as many as 20, disc flowers. Ray flowers are lacking. The 10 to 14 involucral bracts are often brown or purplish. Achenes are granuliferous. Flowers bloom during August and September. Seeds mature during September and October. Plantings of this sage in valley lowlands of central Utah have bloomed profusely, but none of the plants produced mature seed.

Timberline sagebrush covers approximately 100 mi$^2$ (27 000 ha) between 8,500 and 11,000 ft (2 600 and 3 350 m) elevation in high mountainous areas of central Colorado, western Wyoming, and the central Sierras of California. This species is usually found growing in deep soils along the margins of forests. It is also found in other western States, particularly in the high mountains of Utah and Nevada.

### *ARTEMISIA TRIDENTATA* NUTT. (BIG SAGEBRUSH)

Big sagebrush is a highly polymorphic species with numerous ecotypes and biotypes. Three subspecies (*tridentata, wyomingensis*, and *vaseyana*) are generally recognized and will be discussed individually following the general presentation of the species. The big sagebrush complex is composed of aromatic, evergreen shrubs ranging in size from dwarf to tall, arborescent forms up to 15 ft (4.5 m) tall. The lower forms generally have several main stems arising from the base, whereas the tall forms often have a single short trunk. Older branches are covered with a gray to brown or black shredded bark. Younger branches and leaves have a white to gray tomentum that gives the plants a silvery cast.

Typical leaves are narrowly cuneate or oblanceolate and terminate with three blunt teeth at their truncate apexes. However, considerable variation occurs, ranging from linear, entire leaves with rounded to acute apexes, to broadly cuneate leaves with varying number of teeth or shallow lobes. The leaves also range in size from 0.08 to 0.8 inch (2 mm to 2 cm) broad and 0.4 to 2.6 inches (1 to 6.5 cm) long. Normally, leaves on vegetative shoots are more characteristic and less variable than those on flowering shoots. Also, persistent leaves are less variable than leaves of the spring growth flush, which are shed by midsummer. Heads of this species contain three to eight disc flowers each and are arranged into leafy panicles with erect or sometimes drooping branches. In some forms, the inflorescence becomes spicate. Blooming occurs from July to October. Seeds mature in October, November, and December.

Big sagebrush is the most widespread and common shrub of western North America, especially in the Great Basin. It covers approximately 226,400 mi$^2$ (58.7 million ha) in the 11 western States, and grows in a variety of soils on arid plains, valleys, and foothills to mountain slopes from 1,600 to 11,200 ft (500 to 3 400 m). Although it is fairly tolerant of some alkaline and acid soils, its optimum growth is in deep, fertile, alluvial loams.

*Artemisia tridentata* ssp. *tridentata* (basin big sagebrush) is an erect, heavily branched, unevenly topped shrub. This subspecies has trunklike main stems. Shrubs range between 3.3 and 6.6 ft (1 to 2 m) in height. However, some forms may reach 15 ft (4.5 m) in suitable habitats. Mature shrubs are the largest members of the big sagebrush complex. The evergreen, vegetative leaves are narrowly lanceolate, up to 2 inches (5 cm) long by 0.2 inches (5 mm) wide, and typically three-toothed at the apex. The leaves of the flowering stems, however, gradually become smaller and may be linear or oblanceolate and entire. The gray-canescent foliage possesses a strongly pungent, aromatic odor. Flowering stems arise throughout the uneven crown and bear numerous flower heads in erect, leafy panicles. The heads contain three to six small yellowish or brownish, trumpet-shaped, perfect-disc flowers. The narrowly campanulate involucre consists of canescent bracts 0.12 to 0.16 inch (3 to 4 mm) long and about 0.08 inch (2 mm) wide that form four to five overlapping series around each head. The outermost bracts are less than a fourth as long as the innermost bracts. Flowering occurs from late August to October. Seed matures, depending on site, from October to November.

Basin big sagebrush was at one time the most abundant shrub in western North America on lowland ranges. It normally occurs on dry, deep, well-drained soils on plains, valleys, and foothills below 7,000 ft (2 000 m) elevation. Vigorously growing basin big sagebrush is considered indicative of productive ranges because it often grows in deep, fertile soil. This subspecies has generally been regarded as intolerant of alkali, but there are ecotypes that grow in relatively high alkalinity in association with such alkali-tolerant plants as black greasewood, shadscale saltbush, and saltgrass (*Distichlis stricta*). Plants with strikingly reflexed drooping branches of inflorescence are found throughout the range of ssp. *tridentata*. These have been termed *A. tridentata* ssp. *tridentata* f. *parishii*.

*Artemisia tridentata* ssp. *vaseyana* (mountain big sagebrush) is normally a smaller shrub than basin big sagebrush. Its main stem is usually divided at or near the ground, and it tends to have a spreading, evenly topped crown. The vegetative branches are usually less than 3.3 ft (1 m) high and sometimes layer at the base. There are, however, ecotypes at lower elevations that may reach about 6.6 ft (2 m) in height. The persistent vegetative leaves are broadly cuneate to spatulate and are characteristically wider than those of basin big sagebrush. When looking down at this shrub, the terminal leaves on each twig appear to be distinctly whorled. Subspecies *tridentata* does not show this trait, but ssp. *wyomingensis* shows the trait to some extent. Normally, the leaves are 0.8 inch (2 cm) long, 0.2 inch (5 mm) broad, but in form *spiciformis* may reach 2.6 inches (6.5 cm) long and 0.8 inch (2 cm) broad. Crushed leaves emit a rather pleasant mintlike fragrance in contrast to the more pungent odor of both basin and Wyoming big sagebrush. Flower heads are arranged into narrow, often dense panicles. The heads contain five or six trumpet-shaped, perfect-disc flowers. The broadly campanulate involucre consists of numerous canescent overlapping bracts, 0.2 inch (5 mm) long and 0.12 to 0.16 inch (3 to 4 mm) wide. The outermost bracts are less than half as long as the innermost. Some strains of mountain big sagebrush start blooming as early as July and thus may be in bloom up to 6 weeks earlier than either basin or Wyoming big sagebrush. Seed matures from September through October.

In the Intermountain West, mountain big sagebrush occurs in the upper elevational range of the big sagebrush zone in deep, well-drained soils on mountain slopes from below 4,600 ft (1 400 m) for f. *xericensis* and at elevations over 9,800 ft (3 000 m) for f. *spiciformis*. The form *xericensis* is unevenly topped and grows in relatively dry sites similar to basin and Wyoming big sagebrush. Chromatographically, cytologically, and phenologically, *xericensis* most closely resembles ssp. *vaseyana*. The form epithet "*xericensis*" has not been validly published. Hanks and others (1973) used an analogous term: low elevation *vaseyana*. Form *spiciformis* has larger flower heads and leaves than typical *vaseyana* and is found at higher elevations in the cooler, more mesic sites. Subspecies *vaseyana* grows in slightly acid to slightly alkaline soils. Unlike ssp. *tridentata*, *vaseyana* is rarely associated with any of the saltbushes.

*Artemisia tridentata* ssp. *wyomingensis* (Wyoming big sagebrush) is the most xeric subspecies of *A. tridentata*. Occasionally, all three subspecies may be found growing together. Whenever it is found associated with ssp. *tridentata*, ssp. *wyomingensis* is growing in the poorer, more shallow soils. Subspecies *wyomingensis* is a low shrub usually less than 39 inches (1 m) in height. It has an uneven top with flower stalks arising throughout the crown like ssp. *tridentata*. Its main stems branch at or near the ground level like ssp. *vaseyana*, but it does not layer. Leaves are 0.4 to 0.8 inch (1 to 2 cm) long, narrowly cuneate to cuneate. Flower heads contain three to six disc flowers and are arranged into panicles narrower than the paniculate inflorescence of *tridentata* and wider than the spicate inflorescence of *vaseyana*. Flowering and seed ripening take place later than *vaseyana* and earlier than *tridentata*. Wyoming big sagebrush is abundant throughout the Intermountain region and east of the Continental Divide in Montana, Wyoming, and parts of Colorado in dry, shallow, gravelly soil, usually from 5,000 to 7,000 ft (1 500 to 2 100 m). In Idaho, this subspecies is found from 2,500 to 6,500 ft (760 to 1 980 m) in the hotter, drier portions of the State.

### *ARTEMISIA TRIPARTITA* RYDB. (THREETIP SAGEBRUSH)

Threetip sagebrush is a rounded, evergreen shrub up to 3.3 ft (1 m) high. It may have a simple, trunkline main stem or many branches arising from the base. The bark on young branches is canescent, but becomes shredded and grayish, light brown to dark brown or black on older stems. This species can layer, sometimes sprouts back after a burn, and may sprout from the stump following herbicide treatments. Leaves of the vegetative branches are canescent, 0.2 to 1.6 inches (0.5 to 4 cm) long, and typically deeply divided into three linear or narrowly linear-lanceolate lobes, which in turn may be three-cleft. Some of the upper leaves are often entire. Crushed foliage emits a pungent odor. Flower heads contain 3 to 11 disc flowers and are normally arranged into panicles. Ray flowers are lacking. Each head is subtended by 8 to 12 canescent involucral bracts. Achenes are resinous-granuliferous. Blooming occurs from July to September.

Threetip sagebrush covers approximately 13,000 mi$^2$ (3.4 million ha) in the Northern Rocky Mountains and Great Basin States from British Columbia south through Montana and Wyoming to Colorado and west to Washington, Oregon, northern Nevada, and northern Utah at elevations between 3,000 and 9,000 ft (900 and 2 750 m). In some places, particularly in Idaho, this species occurs between the lower, hot, dry sites dominated by Wyoming big sagebrush and the higher, cooler sites dominated by mountain big sagebrush.

*Artemisia tripartita* ssp. *rupicola* (Wyoming threetip sagebrush) is a dwarf shrub with decumbent branches that rarely grow over 6 inches (1.5 dm) tall. It is frequently found layering and may have a crown spread of 12 to 20 inches (3 to 5 dm). Leaves of the vegetative branches are often 1.2 inches (3 cm) long and deeply divided into linear lobes, each at least 0.04 inch (1 mm) wide. Flower heads bear 3 to 11 disc flowers and are arranged into leafy, narrowly racemose panicles. Flowers bloom in late August and September. Seed ripens in October. Wyoming threetip sagebrush has a rather limited range. It occurs on rocky knolls from 7,000 to 9,000 ft (2 430 to 2 740 m) in elevation in central and southeast Wyoming. Brunner (1972) reported this subspecies also occurs in southern Oregon but has not yet been found in Nevada. It typically grows on sites adjacent to those of mountain big sagebrush.

*Artemisia tripartita* ssp. *tripartita* (tall threetip sagebrush) is a freely branching shrub up to 3.3 ft (1 m) high. It can layer easily when the conditions are right, but is seldom found layering in the field. After burning, it sometimes sprouts. Leaves of the vegetative branches are 0.6 to 1.6 inches (1.5 to 4 cm) long and deeply divided into three linear lobes less than 0.04 inch (1 mm) wide. Flower heads bear four to eight disc flowers and are arranged in panicles that may sometimes be reduced to a spicate form. Flowers bloom in late August and September. Seeds ripen in October. This subspecies occurs in dry, well-drained soils at 3,000 to 7,500 ft (900 to 2 300 m) elevation from British Columbia south through Washington to northern Nevada and eastward to northern Utah and western Montana.

## Sagebrush-Soil Relations

Hironaka (1979) pointed out that edaphic considerations are very important in the distribution of sagebrush taxa. Although there are many exceptions, general distribution of sagebrush is related to soil moisture, temperature, depth, and parent material. Some of his specific observations regarding soil relations in the Pacific Northwest are summarized in the following paragraphs.

In general, *Artemisia tridentata* ssp. *tridentata* tends to occupy the deep soils with minimal development in the low to moderate precipitation zone, whereas ssp. *wyomingensis* occupies soils of moderate depth. As moisture conditions and temperature improve with increase in elevation, ssp. *vaseyana* dominates until it gives way to f. *spiciformis* on deep soils at high elevations.

The position of *Artemisia tripartita* ssp. *tripartita* along the moisture gradient overlaps the upper portion of *A. tridentata* ssp. *wyomingensis* and the lower portion of ssp. *vaseyana*. Apparently, it is not associated with a particular kind of soil.

On shallow soils, dwarf sagebrush species replace the tall species. *Artemisia nova* occupies the lower position along the moisture gradient and is restricted to limestone-derived soils in the drier areas. Where *A. arbuscula* is associated with *A. nova*, the former consistently occurs in the cooler and higher moisture situations. *Artemisia arbuscula* also occurs on shallow, noncalcareous soils with strongly developed claypans in southwestern Idaho and eastern Oregon. These soils are supersaturated during the spring, but during the summer the plants are under considerable moisture stress.

*Artemisia longiloba* occurs in habitats similar to those that support *A. arbuscula* on shallow soils with claypans. Sometimes both species are found in the same stand. *Artemisia rigida* also occurs on similar habitats, but on the more shallow and rocky portions.

# CLASSIFICATION OF SAGEBRUSH ECOSYSTEMS

The need to classify vegetation and land units has long been recognized by natural resource managers, resulting in the development and use of numerous classification systems. Unfortunately, such classifications have stressed current site occupancy and identity by a few commercially important plants. Little consideration has been given to the successional status of existing vegetation or to potential productivity of the environment as reflected by the climax vegetation (Mueggler and Stewart 1980).

The range site classification developed by Dyksterhuis (1949) was adopted by the Soil Conservation Service, and in recent years by the Bureau of Land Management. Although the basis of this classification is climax vegetation, emphasis is placed on site productivity, and nomenclature is descriptive of site and vegetation (Tisdale and Hironaka 1981).

During the past decade, the habitat type concept of classification developed by Daubenmire (1952) has gained increasing acceptance, particularly by the Forest Service. This system stresses the use of the entire climax plant community as an environmental integrator, permitting identification of habitats with similar biotic potentials. Consequently, a particular habitat type has the potential for supporting the same climax vegetation regardless of the plant communities that presently occupy the area. Although vegetation is primarily used to identify and characterize the habitat type, knowledge of soil relations is important, especially where the original vegetation has been altered by grazing, fire, or other manipulations (Tisdale and others 1969). However, different soils may be capable of supporting the same climax vegetation, but with varying levels of productivity.

The habitat type is generally named after the unique combination of dominants in the overstory and understory. Factors other than climax vegetation may be used to delineate areas of similar potential, but they are not usually as satisfactory for assessment of comparable environments. Climax vegetation reflects the environment and provides a means of recognizing similar areas. Although soils and other factors are also useful in classification, vegetation is most easily observed and is the basic resource being directly managed. A binomial nomenclature system is usually adequate, but sometimes a trinomial is necessary (Hironaka and Fosberg 1979).

Sagebrush-grass communities have received considerable study, particularly in the Pacific Northwest (Passey and Hugie 1962; Franklin and Dyrness 1969; Schlatterer 1972; Hall 1973; Lewis 1975). But classification based strictly on the habitat type concept has been largely limited to work by Daubenmire (1970), Winward (1970), Zamora and Tueller (1973), Bramble-Brodahl (1978), Hironaka (1979), Hironaka and Fosberg (1979), Mueggler and Stewart (1980), and Tueller (unpublished manuscript). Figure 2 is an expansion of the compilation by Hironaka (1979) for Idaho, Oregon, and Washington to include Montana, Nevada, and Wyoming.

Identical or similar habitat types, especially if they occur in widely separated areas, may be only superficially alike. This stems from the practice of naming habitat types after the unique combinations of dominant and codominant species without sufficient regard for lesser species that may have considerable influence on characteristics and dynamics of the community. Accordingly, specific descriptions of the various habitat types (such as Daubenmire 1970; Zamora and Tueller 1973; Hironaka and Fosberg 1979; Mueggler and Stewart 1980) should be consulted before similarity is assumed and successful management prescriptions are widely extrapolated. If significant differences exist, management must be adjusted to accommodate them.

Obviously, the list of sagebrush-grass habitat types is far from complete. Utah and Colorado have been largely ignored, as well as several other western States. It is estimated that not more than half of the existing habitat types are included above. Because of the numbers involved, and dearth of specific information, individual management prescriptions cannot be developed for or applied to each habitat type at the present time. Rather, an attempt will be made in this publication to develop general guides for sagebrush-grass ranges with necessary modification tailored to peculiarities of certain habitat types.

**Dwarf sagebrush group**

1. *A. arbuscula* ssp. *arbuscula/Agropyron spicatum* (I,O,W,M,N)
2. *A. arbuscula* ssp. *arbuscula/Festuca idahoensis* (I,O,W,M,N)
3. *A. arbuscula* ssp. *arbuscula/Poa sandbergii* (I)
4. *A. arbuscula* ssp. *arbuscula/Stipa thurberiana* (N)
5. *A. arbuscula* ssp. *arbuscula/Purshia tridentata/Agropyron spicatum* (N)
6. *A. arbuscula* ssp. *thermopola/Festuca idahoensis* (I)
7. *A. longiloba/Agropyron spicatum* (Wy)
8. *A. longiloba/Festuca idahoensis* (I,O,N,Wy)
9. *A. nova/Agropyron spicatum* (I,N)
10. *A. nova/Festuca idahoensis* (I)
11. *A. nova/Agropyron inerme* (N)
12. *A. nova/Stipa comata* (N)
13. *A. nova/Oryzopsis hymenoides* (N)
14. *A. rigida/Poa sandbergii* (I,O,W)

**Tall sagebrush group**

1. *A. cana* ssp. *viscidula/Agropyron caninum* (Wy)
2. *A. cana* ssp. *viscidula/Festuca idahoensis* (I,Wy)
3. *A. rothrockii-A. tridentata* ssp. *vaseyana* f. *spiciformis*/mt. forb (Wy)
4. *A. tridentata* ssp. *tridentata/Symphoricarpos oreophilus-Agropyron spicatum* (Wy)
5. *A. tridentata* ssp. *tridentata/Agropyron spicatum* (I,O,W,M)
6. *A. tridentata* ssp. *tridentata/Elymus cinereus* (I,O,W)
7. *A. tridentata* ssp. *tridentata/Festuca idahoensis* (I,O,W)
8. *A. tridentata* ssp. *tridentata/Poa sandbergii* (O,W)
9. *A. tridentata* ssp. *tridentata/Stipa comata* (I,W,N)
10. *A. tridentata* ssp. *vaseyana/Agropyron spicatum* (I,O,M,Wy)
11. *A. tridentata* ssp. *vaseyana/Festuca idahoensis* (I,O,M,Wy)
12. *A. tridentata* ssp. *vaseyana/Festuca scabrella* (M)
13. *A. tridentata* ssp. *vaseyana/Stipa comata* (I,Wy)
14. *A. tridentata* ssp. *vaseyana/Symphoricarpos oreophilus/A. spicatum* (I,Wy,N)
15. *A. tridentata* ssp. *vaseyana/Symphoricarpos oreophilus/F. idahoensis* (I,Wy,N)
16. *A. tridentata* ssp. *vaseyana/S. oreophilus/Carex geyeri* (I)
17. *A. tridentata* ssp. *vaseyana* f. *spiciformis/Bromus carinatus* (I)
18. *A. tridentata* ssp. *vaseyana* f. *spiciformis/Carex geyeri* (I)
19. *A. tridentata* ssp. *vaseyana* f. *spiciformis/Festuca idahoensis* (I)
20. *A. tridentata* ssp. *vaseyana* f. *xericensis/Agropyron spicatum* (I)
21. *A. tridentata* ssp. *vaseyana* f. *xericensis/Festuca idahoensis* (I)
22. *A. tridentata* ssp. *wyomingensis/Agropyron spicatum* (I,O,M)
23. *A. tridentata* ssp. *wyomingensis/Poa sandbergii* (I)
24. *A. tridentata* ssp. *wyomingensis/Sitanion hystrix* (I)
25. *A. tridentata* ssp. *wyomingensis/Stipa thurberiana* (I)
26. *A. tridentata* ssp. *wyomingensis/Stipa comata* (I)
27. *A. tripartita* ssp. *tripartita/Agropyron spicatum* (I)
28. *A. tripartita* ssp. *tripartita/Festuca idahoensis* (I,W,M)
29. *A. tripartita* ssp. *tripartita/Stipa comata* (I,W)

**Figure 2.—List of sagebrush-grass habitat types reported for Idaho (I), Oregon (O), Washington (W), Montana (M), Nevada (N), Wyoming (Wy).**

## CONDITION AND TREND

### General Considerations

Range condition or health is the status of vegetal cover and soil in relation to a standard or ideal for a particular habitat type or site (Ellison and others 1951). Trend is change in condition. Condition and trend are recognizable by certain indicators that can be seen in soil and vegetation. These indicators help to interpret past and current changes in the ecosystem, and often suggest what may be expected in the future.

Reliable judgment of condition and trend is essential to effective evaluation of the success or failure of range management practices. Consequently, the range manager must be able to identify the plants and habitat types or sites, to understand ecological principles including patterns of and reasons for change, and to properly interpret change as a basis for needed adjustment in management prescriptions.

Soil stability is an essential requirement of satisfactory condition. In other words, vegetal cover must be sufficient to protect the soil from accelerated erosion. Besides quantity of vegetation, quality is important and is usually satisfied by a mixture of perennial grasses and forbs.

Judgment of range condition usually must be made in relation to pristine. For the most part, the best approximation is a relic area that has never been grazed by livestock or otherwise disturbed. However, this does not mean that pristine condition is the management objective. It serves only as a guide to indicate what quality and quantity of vegetation the area is capable of supporting, character of the litter cover, and normal appearance of the surface soil. Comparisons can be made only between ranges of similar potential; therefore, judgment of condition should be preceded by classification of range ecosystems into habitat types or range sites.

Fluctuations in weather must be accepted as normal events whose effects must be considered when judging range condition. Variations in amount of precipitation and patterns of distribution greatly affect plant development and yield (Blaisdell 1958), but their influence on soil stability is usually minor.

Trend may result from some degree of change in any component of the ecosystem. For practical purposes, however, only soil and vegetation need be considered in assessment of trend, which is simply the recognition of the nature, rapidity, and direction of ecological change. In determining trend, one must distinguish between those cumulative changes that produce a real difference in condition and those that are mere fluctuations. For example, a large crop of seedlings of desirable perennial species may reflect only a temporarily favorable combination of circumstances. A surer indication of upward trend would be plants of successively older age classes in addition to the seedlings (Ellison and others 1951). These authors have made a comprehensive evaluation of 21 important indicators of range condition and trend including cover, bare soil surface, observed movement of soil, trampling displacement, soil remnants, erosion pavement, lichen lines, active gullies, wind-scoured depressions, aeolian deposits, alluvial deposits, vegetal composition, age classes, annual weeds, invasion of bared surfaces, vegetation in gullies, rill-channel ridges, accessibility of palatable species, relics, hedged shrubs, and current utilization. These indicators provide clues to events that have happened, are happening, or will happen on the range-watershed. Although they have particular application to the subalpine zone, most are worthy of serious consideration as indicators of condition and trend on any rangeland grazed by livestock.

### Sagebrush-Grass Ecosystems

Information on sagebrush-grass ecosystems is meager; however, general guides for recognizing condition and trend were developed in southern Idaho by Pechanec and Stewart (1949). These can be broadly used by a manager to make reasonable judgments of range condition and trend for a variety of habitat types or sites, especially those at intermediate and low elevations.

#### CONDITION

Condition may be judged by such characteristics as relative vigor and abundance of good and poor forage plants, and extent of soil erosion. Four condition situations can be readily recognized:

1. Sagebrush with a good understory of perennial grasses and forbs (fig. 3). Such ranges have not been greatly changed from their original condition, and forage production is not far below the potential. The understory is composed of palatable perennial grasses and forbs, which make up more than a third of the total vegetation and are abundant in the spaces between sagebrush plants. However, they usually do not form a solid cover and some bare ground can be expected. Sagebrush is in open stands. Soils are essentially unchanged from their original condition, with no observable erosion. Condition is classed as good or excellent.

**Figure 3.—Closeup of an *Artemisia tripartita* ssp. *tripartita*/ *Agropyron spicatum* habitat type in excellent condition near headquarters of the U.S. Sheep Experiment Station, Dubois, Idaho. The prominent forb is *Balsamorhiza sagittata*.**

2. Sagebrush with a sparse understory of perennial grasses (fig. 4). On these ranges perennial grasses have been reduced to a scattered stand, sagebrush has greatly thickened, and perennial forbs are virtually lacking. Erosion is often severe, but on level sites soil may be in relatively good condition because of protection by the dense sagebrush cover. Forage production is light and mostly unavailable to grazing animals. Range condition is poor to fair.

3. Sagebrush with an understory of annual grasses and weeds. These ranges are characterized by a dense stand of sagebrush with an understory of annuals. Perennial grasses are present only

**Figure 4.—Same habitat type as figure 3, this time in fair condition. Note the absence of forbs.**

as scattered individuals. Severe erosion has often occurred as indicated by erosion pavement or pedestaled plants. On level ground, however, the soil surface may be rather well preserved even though the forage cover is depleted. The already poor forage production is unstable in quantity from year to year. Range condition is classed as very poor to poor.

4. Ranges with sagebrush replaced by cheatgrass or other annuals. Ranges on which sagebrush and other original species have been destroyed by recurrent fires, cultivation, or grazing, now support nearly pure stands of annual grasses or weeds. Soil losses are often severe; however, soil condition of some cheatgrass ranges may be good. Although forage production on such ranges can be high, it is highly variable and may be extremely low in years of scanty precipitation.

**TREND**

Knowledge of trend is essential in planning and evaluating a grazing program. For each of the four categories described above, trend in condition is shown by distinct plant or soil indicators. With the exception of accelerated erosion, a single indicator is seldom sufficient to depict trend. Although a careful inspection may reveal apparent trend, observation of indicators over a series of years may be necessary for definite confirmation.

1. Sagebrush with a good understory of perennial grasses and forbs. **Improvement or maintenance** of ranges already in satisfactory condition will be accompanied by few or no indicators of trend. Palatable grasses and forbs should be vigorous, and a few seedlings may be in the process of becoming established. Few sagebrush seedlings are evident, and soil is stable.

Indicators of **downward trend** on good-condition threetip sagebrush (*Artemisia tripartita*) range at the U.S. Sheep Experiment Station in southeastern Idaho were precisely documented by Pechanec (1945). The first signs became evident within 3 years after the pastures were overstocked. The indicators in order of occurrence were: decrease in vigor of palatable perennial forbs and the fine grasses, increase in number and size of annuals, decrease in vigor of the robust perennial bunchgrasses, establishment of numerous young sagebrush plants in the openings, death of parts of perennial forb and grass clumps, and excessive pedestaling of bunchgrasses. Many of these changes are illustrated by the photographs in figure 5.

2. Sagebrush with a sparse understory of perennial grasses. **Upward trend** is indicated by increase in vigor of perennial grasses and forbs and establishment of a few seedlings. Although a few sagebrush seedlings may be present, production of sagebrush usually declines as a result of loss in vigor of established plants. There should be a slight accumulation of litter and less prominent pedestaling of bunchgrasses. Such changes are illustrated in figure 6. **Downward trend** is indicated by increase in sagebrush and annuals such as cheatgrass. Such changes are accompanied by a decrease in palatable perennial grasses and forbs and establishment of young sagebrush plants in the openings.

3. Sagebrush with an understory of annuals or range with sagebrush replaced by annuals. Natural **improvement** of vegetation on such areas will usually be extremely slow; consequently, upward trend must be judged primarily by increase in litter and stabilization of the soil. Establishment of a few seedlings of perennial grasses and forbs may occur. **Downward trend** may be indicated by low vigor of annuals, replacement of cheatgrass by weeds, and by active gully and wind erosion.

Although the above indicators of condition and trend generally apply to sagebrush-grass vegetation, they have only limited value in habitat types dominated by such palatable species as black sagebrush (*Artemisia nova*). As described by Hutchings and Stewart (1953), **upward trend** is indicated by an increase in black sagebrush and palatable perennial grasses such as Indian ricegrass (*Oryzopsis hymenoides*), whereas a decrease in these species, along with an increase in such unpalatable species as small rabbitbrush (*Chrysothamnus viscidiflorus* ssp. *stenophyllus*), denotes a **downward trend**.

Special situations must be recognized and evaluated by different standards. For example, a depleted area of sagebrush-grass range that has been satisfactorily revegetated with desirable exotic species can be considered to be in good condition provided soil is stable and yield of vegetation is near potential for the site and in line with management objectives. These may be considerably different from those of native sagebrush-grass range. In this paper, however, condition and trend for the most part are considered in relation to natural vegetation and deviations therefrom. Deliberate manipulations for specific management goals are recognized but not addressed in detail.

Condition and trend of sagebrush-grass ranges cannot be adequately evaluated without an examination of included riparian and aquatic areas, which may be particularly sensitive indicators of what is happening on the range as a whole. Not only do livestock tend to concentrate in such areas and have serious direct impacts on vegetation, soil, and water quality, but these areas can also be severely damaged by runoff and erosion from surrounding poor condition range. It is axiomatic, then, that a sagebrush-grass range unit is not in good condition unless the riparian and aquatic portions are also in satisfactory condition.

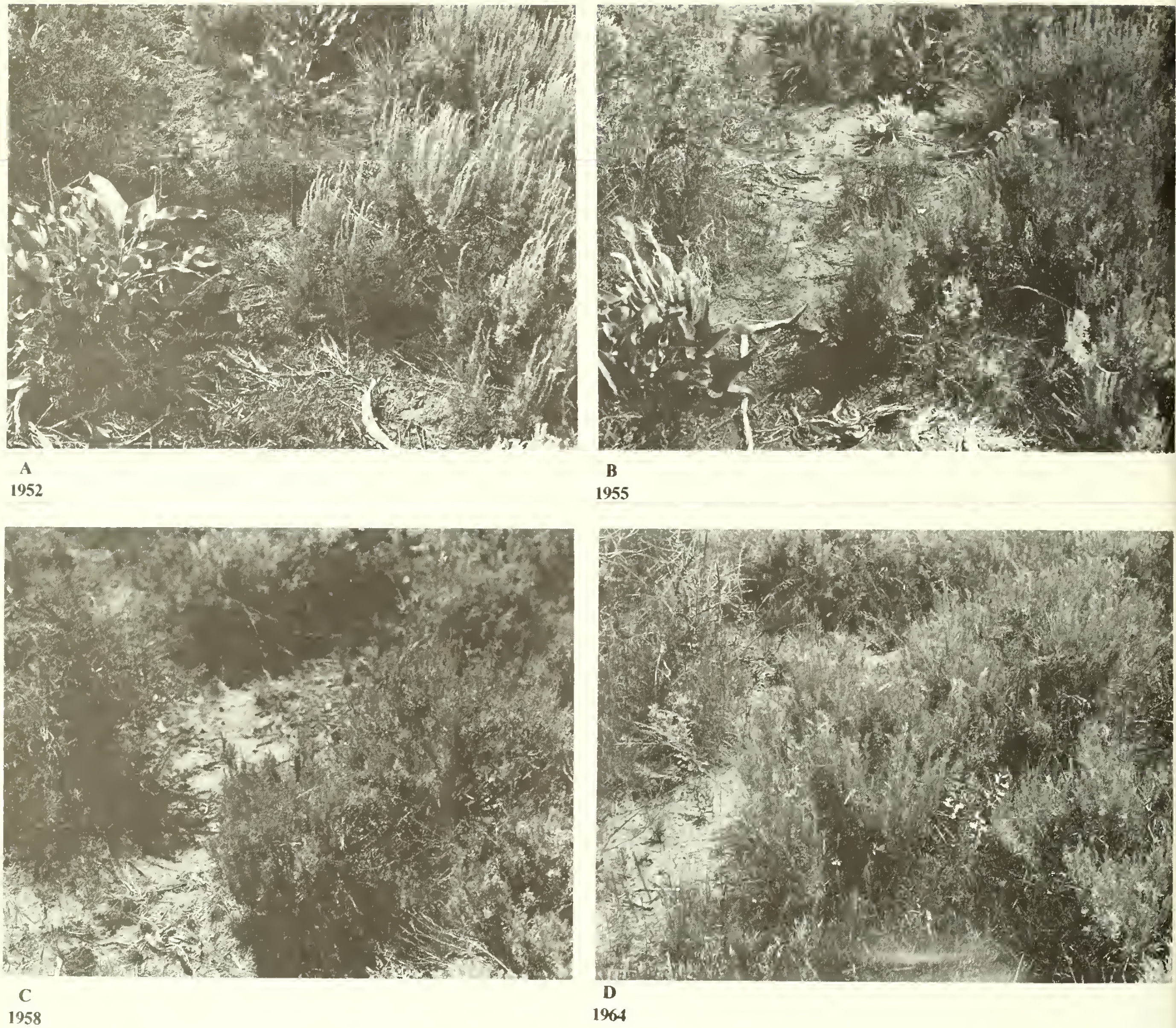


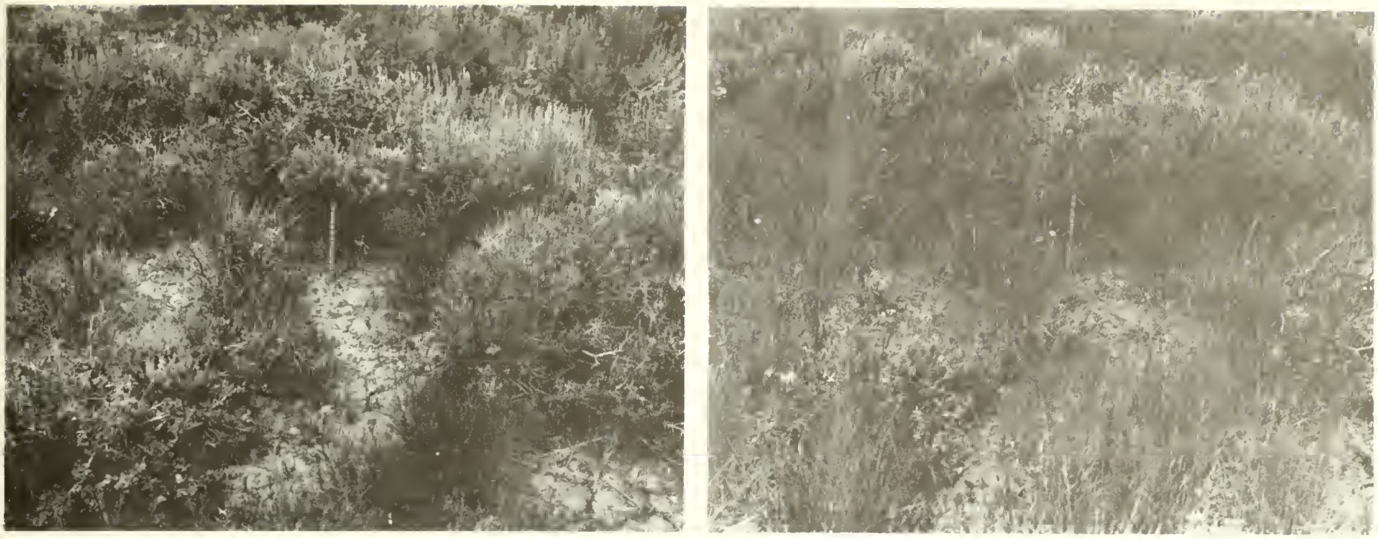

**Figure 5.—Plot in *Artemisia tripartita/Agropyron spicatum* habitat type showing deterioration from excellent to poor condition as a result of high-intensity spring use by sheep. Grass in photo D is largely cheatgrass (from Laycock 1967).**

## MANAGEMENT

Management objectives for sagebrush-grass ranges may be described in a number of ways: wise multiple use, maintenance or improvement of vegetation and soil, or perhaps optimum sustained-yield of livestock and wildlife consistent with other uses and values. Although emphasis may vary with specific conditions or situations, it seems logical to direct primary attention to conservation of the basic resource, soil and vegetation. Having these factors in natural or pristine condition is perhaps a theoretical goal, for it must be recognized that such condition can seldom be achieved under practical use, especially livestock grazing that is foreign to the original ecosystem. Furthermore, a considerable portion of the sagebrush-grass area has been so modified by past use that restoration to the natural condition will not be possible during the foreseeable future, even under intensive management. Nevertheless, the pristine concept should be retained as a guide to indicate possible vegetation and soil conditions for particular habitat types or range sites.

Although stable soil is always a prerequisite to satisfactory condition, vegetation is more easily observed and measured. Consequently, effectiveness of management is usually judged by vegetal response. Despite great diversity in the various habitat types of sagebrush-grass range, the prevalent **now** situation is too much sagebrush and other low-value shrubs, too many annuals, and not enough perennial grasses and forbs. Simply stated, then, vegetation management often requires a reduction is sagebrush and an increase in perennial grasses and forbs.

If deterioration has not progressed too far, it may be possible to use grazing management itself to bring about needed improvement in vegetation. However, sagebrush is an aggressive, long-lived shrub, and direct control measures followed by revegetation with herbaceous species may be necessary to restore the range to a satisfactory condition.



A
1952

B
1964

**Figure 6.—Increase in ground cover and production of perennial grasses and forbs as a result of shifting from spring to fall grazing by sheep (from Laycock 1967).**

## Sagebrush Control

Control of undesirable plants is often essential to substantial improvement of sagebrush-grass range. Normally, sagebrush is the target species, but control of other low-value shrubs, annuals, or noxious weeds may be necessary. Burning, spraying, and mechanical methods have all been used effectively. Biological measures such as manipulation of insects, diseases, and mammals are also possibilities.

No method is universally the best because sagebrush taxa are highly variable, and they grow under widely different conditions. Suitability of a particular method depends upon such factors as density, height, and age of the sagebrush stand, associated shrubs, amount and kind of grasses and forbs in the understory, topography and rockiness of the area, type of soil and susceptibility to erosion, available equipment, size of the area to be treated, planned use, and personal preference. In choosing a method, the following points are important (Pechanec and others 1965): (1) use a method that will accomplish a satisfactory kill of sagebrush and associated undesirable species; (2) if seeding is not necessary, use a method that causes minimum damage to desirable species of grasses, forbs, and shrubs; (3) if seeding is planned, use a method that kills most of the vegetation and leaves a suitable seedbed; (4) use a method that will not increase erosion hazards; and (5) choose a method that is most economically consistent with the above guidelines.

### BURNING

Fire is a natural component of many sagebrush-grass ecosystems, and any site producing vegetation dense enough to carry a fire has undoubtedly burned many times in its developmental history. Since plant species vary greatly in their response, fire—either natural or deliberately set—can be used to control some species while favoring others. Despite the general tolerance of vegetation and soil to fire, undesirable impacts do occur. These can be minimized if the manager has an understanding of fire ecology that he can use to select the area to be burned and choose the best season for doing so.

Habitat types dominated by such big sagebrushes as *A. tridentata* ssp. *tridentata*, *vaseyana*, and *wyomingensis*; *A. tripartita*; and *A. cana* often provide enough fuel to carry a fire. However, if the understory has been depleted by past abuse or removed by current utilization, there may not be enough fuel for successful burning. Habitat types of the dwarf species (*A. nova, arbuscula, rigida, pygmaea*, and *longiloba*) seldom support enough vegetation to carry a fire, so other methods of plant control will usually be necessary. At any rate, each situation must be carefully examined and evaluated before burning can be prescribed as a plant control measure.

### Ecological Effects

Response of mountain big sagebrush (*A. tridentata* ssp. *vaseyana*) and associated species was studied on a prescribed burn at the U.S. Sheep Experiment Station in southeastern Idaho for 30 years, 1936-66 (Blaisdell 1953; Harniss and Murray 1973). Burning was accomplished according to plan in August 1936. An initial inventory of vegetation was made prior to burning in 1936 with followup observations on permanent plots in 1937, 1939, 1948, and 1966. Prior to burning, the area supported a dense stand of sagebrush, beneath which was an open but fairly continuous stand of perennial grasses. Roughly, the vegetation was 35 percent perennial grasses, 5 percent perennial forbs, 5 percent annual forbs, 40 percent sagebrush, and 15 percent rabbitbrush, horsebrush, and other shrubs. Although absolute values in pounds per acre were determined for the various species, trends were expressed as percentages of production on unburned range.

With a few exceptions, relative production of all grasses decreased the year after burning, and these decreases varied roughly in proportion to burn intensity. Thickspike wheatgrass (*Agropyron dasystachyum*) and plains reedgrass (*Calamagrostis montanensis*) were only slightly affected, but decreases were severe in Idaho fescue (*Festuca idahoensis*) and needle-and-thread (*Stipa comata*), especially on high-intensity burns. Within 3 years thickspike wheatgrass and plains reedgrass made substantial gains on burns of all three intensities, and yields continued to increase during the next 9 years. Idaho fescue, prairie junegrass (*Koeleria cristata*), and needle-and-thread made partial recovery during the first 3 years, and bluegrasses (*Poa sandbergii* and *P. nevadensis*) completely recovered on all but the heavy burn. After 12 years, only Idaho fescue on the heavy burn had not regained its loss. During the following 18 years, however, thickspike wheatgrass, plains reedgrass, bluebunch wheatgrass, and needle-and-thread all decreased, and bluegrasses and Idaho fescue continued to increase. Therefore, 30 years after burning, relative yields of the various grasses were near their preburn levels (fig. 7).

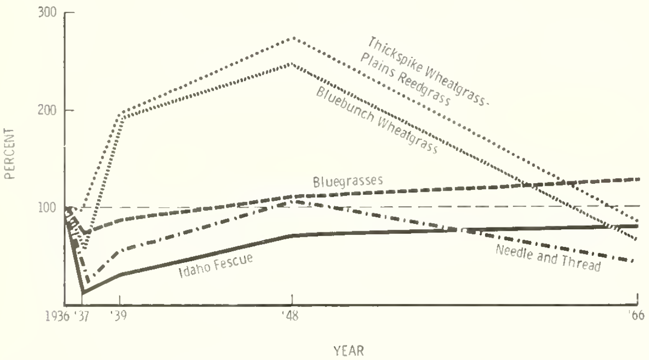



**Figure 7.—Trends of important grass species on a planned burn near Dubois, Idaho, 1936-66. Values are adjusted for the natural variation (a) between burned and unburned plots and (b) between years (from Harniss and Murray 1973).**

Total forbs decreased the year after burning, but they regained their original yield within 3 years. Rhizomatous forbs generally increased the first year, but suffrutescent species (perennial forbs with partially woody stem bases that do not die down to the ground each year), especially buckwheat (*Eriogonum heracleoides*) and pussytoes (*Antennaria* spp.), decreased markedly on burns of all intensity. Rhizomatous species continued to increase through the third year and then decreased. After initial decreases, suffrutescent species increased during the next 9 years and regained much of their original losses.

Sagebrush was practically eliminated, and its reestablishment from seed was slow, whereas rabbitbrush (*Chrysothamnus viscidiflorus* ssp. *puberulus*) and horsebrush (*Tetradymia canescens* var. *inermis*) sprouted profusely. These sprouts quickly regained or surpassed the original size of the shrubs and produced seed for establishment of new plants. Consequently, yield of rabbitbrush and horsebrush was increased by the third year after burning despite the initial decrease. These species continued their rapid increase during the following 9 years, but sagebrush made only slight recovery. Sometime during the next 18 years, however, substantial decreases occurred in rabbitbrush and horsebrush accompanied by a great increase in sagebrush (fig. 8).

Vegetation trends during the 30 years demonstrate the overwhelmingly dominant role of mountain big sagebrush in the community under study. After increasing during the first 12 years following burning, nearly all species of grasses, forbs, and shrubs decreased in yield during the subsequent 18 years as sagebrush regained control of the area.

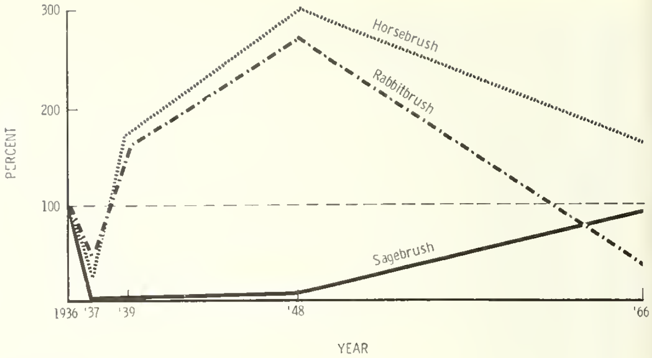



**Figure 8.—Trend of important shrub species on a planned burn area near Dubois, Idaho, 1936-66. Values are adjusted for the natural variation (a) between burned and unburned plots and (b) between years (from Harniss and Murray 1973).**

The ability of mountain sagebrush to reinvade the vigorous stand of grass that became dominant following the burn was somewhat surprising, as Blaisdell (1949) had previously concluded from revegetation studies that good stands of grass established prior to sagebrush suppress the sagebrush seedlings or entirely prevent sagebrush establishment for an indefinite period. However, Frischknecht (1968) indicated that in years of high precipitation sagebrush can invade both grazed and ungrazed stands of crested wheatgrass (*Agropyron cristatum* and *A. desertorum*). Apparently, competition for soil moisture is less severe during such years.

In the following discussion, an attempt is made to provide a more complete description of what happens to sagebrush-grass vegetation after burning. During the early part of the first growing season, it is evident that actual damage to vegetation far outweighs the benefits. Perennial grasses and forbs are clearly lowered in vigor, as old plants are badly broken up and remaining plants are small and scattered. Although rhizomatous species are apparently less damaged than others, even these have poor vigor. Shrubs are represented by only a few sprouts. Much bare ground is exposed, but an abundant growth of annuals may fill many of the openings. As the season progresses, new shoots of rhizomatous grasses and forbs appear, and tuft-forming species begin to stool out; however, scarcely any flower stalks are produced. Grasses and forbs remain green about 2 weeks longer than on unburned areas. The appearance of a typical year-old burn is shown in figure 9A.

During the second year, perennial grasses and forbs continue to increase and vigor is high. Sprouting shrubs are larger, but are still an inconspicuous part of the vegetation. The most noticeable feature of burns during the second growing season is abundant flower stalk production of almost all grasses and forbs (fig. 9B). Why this occurs is not known, but it may be related to a temporary increase in mineral nutrients and increased soil moisture. At any rate, seed is provided for revegetation of areas that may not be supporting a full plant cover.

Total herbage production of grasses and forbs reaches a maximum within a few years after burning, largely as a result of increases in the fire-resistant rhizomatous species. Although this increased production may persist indefinitely, more often it declines in subsequent years. This general decline in grasses and forbs is accompanied by an increase in shrubs and many nonrhizomatous herbaceous perennials.


A
1937


B
1938

**Figure 9.—(A) Plot in the *Artemisia tridentata* ssp. *vaseyana/ Agropyron spicatum* habitat type at the U.S. Sheep Experiment Station 1 year after burning. Grasses are mostly rhizomatous species—*Agropyron dasystachyum* and *Calamagrostis montanensis*. (B) Same plot 2 years after burning. Note the abundant flower stalk production of the grasses.**

Shrubs are apparently more damaged by burning than either grasses or forbs. Not only is the current herbage destroyed by fire, but the aboveground woody parts are either killed or completely consumed, resulting in destruction of stored reserves. This may also be the reason that suffrutescent forbs are more severely damaged than other forbs having no aboveground, perennial parts. However, such species as rabbitbrush, horsebrush, snowberry (*Symphoricarpos oreophilus*), and chokecherry (*Prunus virginiana*) sprout profusely and are only temporarily injured (fig. 10A). Sprouting of bitterbrush (*Purshia tridentata*) is highly variable, ranging from 0 to 60 percent. Apparently, amount of sprouting is related to inherent characteristics and to intensity of burning, which, in turn, is strongly affected by season and soil moisture (Blaisdell and Mueggler 1956b).

With the exception of occasional sprouting by threetip (*A. tripartita*) and silver (*A. cana*), sagebrushes are nonsprouters, so are easily killed by fire. Absence of sagebrush on many areas is an indicator of past burns. Since associated shrubs are able to sprout, at least to some degree, it is significant that sagebrush has been able to maintain a prominent position in the vegetation (fig. 10B).

It is apparent that response to burning within each class—grasses, forbs, or shrubs—is highly variable. If initial effects that are generally injurious to all species are ignored, the following classification, based on sprouting ability of shrubs and growth form of herbs, is fairly reliable for describing response of perennial species:

**Severely damaged.**—Shrubs that are unable to sprout, suffrutescent forbs, and fine bunchgrasses with densely clustered culms such as Idaho fescue and needle-and-thread.

**Only slightly affected.**—Coarse bunchgrasses, fine bunchgrasses with loosely clustered culms such as bluegrasses and squirreltail, forbs that are neither suffrutescent nor rhizomatous, shrubs with a limited sprouting habit.

**Considerably benefited.**—Shrubs with strong sprouting habit, rhizomatous grasses, rhizomatous forbs.

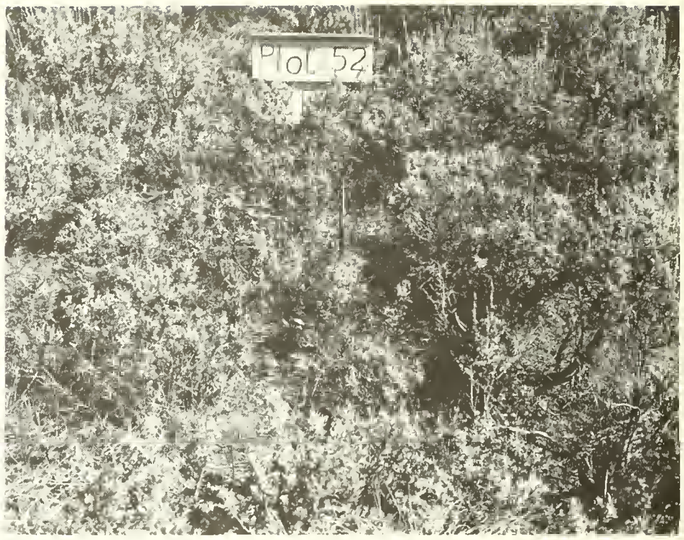
For additional information on effects of burning on sagebrush-grass vegetation, see the review by Wright and others (1979).

Since vegetal response is closely related to burn intensity, early spring or winter burns will be less injurious to most species than those in summer or fall when soil moisture is low and temperatures are high. Summer burns can be especially devastating to grasses and forbs because they destroy herbage before maturity (Blaisdell and Pechanec 1949; Pechanec and others 1954). Sagebrush, the usual target species, is readily killed by fire in all seasons at even light intensities.

Prescribed burning in winter or spring requires relatively dense vegetation and favorable burning conditions; consequently, it may be possible to burn only limited areas during these seasons (Beardall and Sylvester 1974; Neuenschwander 1980). Murray 1980,[1] however, has had considerable success with spring burning on the Upper Snake River Plains. His experience indicates the need for a period of warm, dry weather in early April to remove the winter snowpack and to dry the grass and forb litter. At this time, moisture content of sagebrush leaves and stems is usually low.

[1]Murray, R. B. Data on file. Dubois, ID: U.S. Department of Agriculture, Agricultural Research Service, U.S. Sheep Experiment Station; 1980.

A



B

**Figure 10.—The same plot shown in figure 9. (A) 6 years after burning. Most of the shrubs are rabbitbrush and horsebrush sprouts from the original plants. (B) 30 years after burning. A fairly dense stand of sagebrush now dominates the plot despite conservative grazing management.**

A burn in April 1977 was preceded by an unusually dry winter and followed by an exceptionally wet spring and summer. At the time of the burn, Idaho fescue, thickspike wheatgrass, and some forbs were beginning to turn green. By August shrub, grass, and forb production was 62, 714, and 48 lb/acre (70, 801, and 54 kg/ha) compared to 5,705, 300, and 85 lb/acre (6 392, 336, and 95 kg/ha), respectively, on the adjacent unburned site. The spring and summer of the second year were drier than normal, but production of Idaho fescue was 103 percent of that on the unburned area. Within 2 years, production of forbs on the burn increased from 57 to 181 percent of the unburned.

The advantage of spring burning appears to be the higher level of soil moisture that acts to protect the plants and provide moisture for immediate growth following burning. Incidence of bitterbrush sprouting can be as high as 90 percent. Individual bunchgrasses are seldom burned deep into the crown as often happens during late summer or fall. The moist soils are less susceptible to wind erosion, and rapid growth of the plants further acts to protect the soil from erosion. From an economic standpoint, spring burning is cheaper as it can be accomplished with fewer individuals and without firebreaks in some situations. A disadvantage of spring burning is the higher rate of sprouting for threetip sagebrush—10 percent as compared to less than 1 percent on fall burns.

Effects of fire on soils were reviewed by Mueggler (1976). Ordinarily, nutrients contained in vegetation are released slowly by decomposition of the plant litter; however, burning immediately releases these stored nutrients in the form of volatiles or ash. Nitrogen and sulfur are volatilized by combustion, at least partially, and may be lost to the system. Other nutrients are changed to water-soluble salts, which are immediately available for plant growth.

Change in nitrogen status of the soil is of special interest because of its influence on productivity. Direction and amount of change vary with individual situations. Apparently, nitrogen lost through volatilization is rapidly replaced by increased activity of nitrifying bacteria stimulated by nutrients released by fire. R. B. Murray and H. F. Mayland (1980, unpublished data) determined that nitrates were mineralized in the surface 0 to 2 inches (0 to 5 cm) of soil at a greater rate on a spring burn than on a similar unburned site.

Generally, such primary nutrients as phosphorus, potassium, calcium, magnesium, and a number of micronutrients are added to the soil as a result of burning. However, nutrients contained in the ash are highly water-soluble and may be removed from the site by leaching or surface flow until they are again tied up by vegetation or soil.

Removal of vegetation by fire increases the possibility for soil loss through wind and water erosion. The potential seriousness of such loss depends upon such factors as burn intensity, soil erodibility, topography, frequency of high-intensity wind and rain, and rapidity of vegetation reestablishment. Wind erosion, even on high-intensity burns, is often no more than redistribution of ash until stabilized by rainfall. Water erosion is generally not serious except where torrential storms happen to occur on steep slopes.

## Guidelines for Use

The primary use of fire on sagebrush-grass ranges should be control of dense stands of sagebrush so that the more desirable species can increase. Usually the goal should be roughly consistent with the climax cover that can be attained in a particular habitat type or site. It is true that forage production on a fairly recent burn might surpass that on a similar area in climax condition because of replacement of sagebrush by perennial grasses and forbs. However, ranges that are naturally sagebrush-grass climax cannot be entirely freed of sagebrush for an indefinite period. Repeated burning, especially at close intervals, to maintain such a subclimax stage would probably result in eventual impoverishment of the soil and loss of desirable species.

Prescribed burning will seldom be possible or desirable in the dwarf sagebrush habitat types. For the most part, vegetation is too sparse to carry a fire except under extremely hazardous conditions. Furthermore, many of the dwarf species, especially black sagebrush (*A. nova*) and low sagebrush (*A. arbuscula*), are desirable forage plants for livestock and wildlife. Use of fire may be a possibility in some deteriorated habitat types of low sagebrush, but experimental testing will be necessary before reliable prescriptions can be formulated.

Although numerous habitat types have been described in the tall sagebrush group, in the Intermountain area only five taxa are important from the standpoint of acreage involved and possibilities for prescribed burning: basin big sagebrush (*A. tridentata* ssp. *tridentata*), Wyoming big sagebrush (A. *tridentata* ssp. *wyomingensis*), mountain big sagebrush (*A. tridentata* ssp. *vaseyana*), threetip sagebrush (*A. tripartita* ssp. *tripartita*), and mountain silver sagebrush (*A. cana* ssp. *viscidula*). Habitat types of mountain silver sagebrush probably support sufficient vegetation to allow burning, but these must be studied further before burning can be recommended.

For all practical purposes, then, burning can only be prescribed for habitat types of threetip sagebrush, and basin, Wyoming, and mountain big sagebrushes. However, these represent some 60 percent of the total sagebrush area and include most of the situations where fire should or can be used as a management tool. Furthermore, sufficient experience is available to allow reliable guides for use of fire in these habitat types.

Burning as a range improvement measure should be implemented only after alternatives have been considered and a satisfactory plan has been developed and approved. Where, when, and how to burn should all be addressed—as well as followup management.

**Where.**—Sagebrush range should be burned only where all the following conditions prevail:

1. Soils are stable and slopes are less than 30 percent. Burning seriously increases the danger from erosion by removing protective cover for a considerable time. If topsoil blows or washes away, fertility will be lost, plant roots will be exposed, and a protective vegetal cover will be slow to reestablish.

2. Sagebrush is dense and forms more than a third of the plant cover. Scattered stands of sagebrush do not offer serious competition to grasses and forbs, so its removal allows little range improvement. Also, unless the grass understory is thick, sparse stands of sagebrush provide a scanty supply of fuel and usually cannot be burned except under extremely hazardous conditions.

3. Fire-resistant perennial grasses and forbs form more than 20 percent of the plant cover, or revegetation with desirable species is practicable. If perennial grasses and forbs are not present prior to burning, it will be necessary to establish a suitable cover through seeding.

4. Principal use of the area is livestock grazing or where it has been demonstrated that burning will not adversely affect conditions for wildlife. In addition to providing more forage for both livestock and wildlife, burning often creates improved wildlife habitat by increasing diversity and broadening the food base. It must be recognized, however, that many shrubs, including sagebrush, are necessary for wildlife and should not be destroyed on certain critical areas.

**When.**—Satisfactory burns can be achieved most consistently in early fall. At this time, damage to the nontarget species is tolerable, and weather conditions will generally allow successful burning. Seed of perennial herbaceous species and bitterbrush will have been disseminated by this time, and some may survive the burn to produce seedlings the following year. Preparation of fire lines and other arrangements are expensive, so burning should be accomplished before cool, moist weather arrives in the fall.

Early spring burning will kill sagebrush with minimum damage to other species because temperatures are relatively cool and moisture is relatively high. Timing is critical as conditions that allow burning seldom last for more than a few days. Also, use of fire may be restricted to small areas where sagebrush and other fuels are especially dense. Careful monitoring of fuels and weather, however, may allow successful burning in certain favorable situations. Suppression costs of spring burning are minimal.

Midsummer burning is generally not recommended because it causes maximum damage to perennial grasses. Furthermore, burning at this time increases the chance for serious wind and water erosion by lengthening the time of soil exposure to these elements.

**How.**—Detailed planning is a prerequisite for safe and successful burning. Local and Federal fire laws and regulations must be observed. Information on these an other matters relating to prescribed burning can be obtained form State and Federal land management agencies such as State Department of Lands or Forestry, Bureau of Land Management, and Forest Service. A burning permit is always required.

The plan should contain a description of the area to be burned, weather requirements and proposed time for burning, necessary preburn preparations including construction of firelines, details for carrying out the burn with a list of required men and equipment, and a comprehensive management plan showing how the burned area will be treated in subsequent years in conjunction with adjacent lands.

Adequate firelines must be constructed to prevent escape of the fire. Wright and others (1979)—based on experience of Pechanec and others (1954), Ralphs and others (1976), and Davis (1976)—recommend surrounding the area to be burned with a bulldozed break 10 to 12 ft (3 to 3.7 m) wide. This would then be expanded to about 200 ft (60 m) on the leeward sides by strip backfiring during the morning hours when wind is 5 to 8 mi/h (8 to 13 km/h) and relative humidity is about 40 percent. A pumper is used to extinguish the backfire when the desired width is obtained. A less flexible but perhaps safer method is to construct a second cleared line parallel to, but about 200 ft (60 m) inside, the first. Vegetation between the two lines is then removed by progressive backfiring (Pechanec and others 1954). Backfiring is a critical part of prescribed burning, and all possible precautions should be taken. The main area to be burned should be touched off when air temperature is above 75° F (24° C), relative humidity is 15 to 20 percent, and wind is 8 to 15 mi/h (13 to 24 km/h). Spring burning, however, may require different criteria.

Techniques now in developmental stage may eliminate the undesirable effects of bulldozing firelines (Davis 1976; Ralphs and others 1976). One possibility is the use of a large propane burning unit mounted on a trailer. Vegetation can be burned when moisture is high, and several strips can be burned to achieve the desired width. Another possibility is to spray the proposed firebreak with a contact herbicide while the vegetation is green. Subsequent burning of the sprayed vegetation should produce an adequate fireline. However, such methods cannot be recommended for general use without further study. The Intermountain Region of the Forest Service is testing a new method for starting prescribed fires (USDA Forest Service 1980) that involves a helicopter for dispensing ignited gobs of jelled fuel. This holds much promise for effecting future burning prescriptions.

Considerable effective burning can be accomplished without the use of prepared firelines, providing natural firebreaks are used. Fire will seldom carry in dwarf sagebrush habitat types, so patches of big sagebrush growing in swales surrounded by such fire-resistant vegetation can often be burned safely without preparing firelines. Similarly, early spring burning can often be accomplished with minimal use of prepared firelines (Wright and others 1979).

**Management after burning.**—Proper grazing management following burning is essential. Even accidental burns may be beneficial if grazing is properly managed afterward. On the other hand, anticipated results for the best prescriptions may be seriously modified if destructive grazing practices are allowed.

Most burns should be completely protected from livestock grazing for at least one and possibly two growing seasons. Only a small amount of forage is produced the first year, and grazing may cause serious damage to soil and desirable perennials. Despite the apparent abundance of green herbage, most plants are low in vigor and will be further weakened or destroyed by grazing. Furthermore, grazing will disturb the inadequately protected soil and allow increased water and wind erosion.

Protection through the second growing season will allow restoration of vigor and the typical heavy seed production of perennial grasses and forbs. However, after seed dissemination, light grazing may serve a useful purpose in helping to plant the seed.

On areas where cheatgrass is abundant, special measures may be necessary to prevent recurrent fires, which would be devastating to perennial grasses and forbs already weakened by burning. Also, areas with only a poor stand of desirable perennials prior to burning will probably require seeding to provide satisfactory forage production and delay return of sagebrush or other unwanted species.

Accidental burns should, of course, be protected and managed in the same way as prescribed burns. If this is done, damage will be minimized and what at first appears to be a tragedy may actually result in significant improvement.

## SPRAYING

Control of sagebrush with herbicides became common in the early 1950's when it was demonstrated that 2,4-D, a plant growth regulator, could effectively kill big sagebrush (Evans and others 1979). Although numerous other chemicals such as 2,4,5-T and Picloram were developed concurrently or in subsequent years, 2,4-D has generally been most effective and most economical for sagebrush control and so has received widespread use. It has not been proven toxic to humans or animals, is readily degradable, and is approved by the Environmental Protection Agency for use on sagebrush rangelands.

Because effective control of big, low, black, silver, threetip, and alkali sagebrushes with 2,4-D has been reported (Pechanec and others 1965; Blaisdell and Mueggler 1956a; Eckert and Evans 1968), it is assumed that all sagebrushes are susceptible to this chemical. Results generally indicate that sagebrush is most vulnerable in the spring when it is actively growing. This corresponds roughly to the period when small bluegrasses come into head until they are drying and losing their green color.

Satisfactory results can usually be obtained with 2 lb acid equivalent of a low-volatile ester formulation of 2,4-D per acre (2.25 kg/ha). (Incidentally, this treatment will also be effective in controlling wyethia [*Wyethia amplexicaulis* and *W. helianthoides*], an undesirable forb often associated with mountain big sagebrush [Mueggler and Blaisdell 1951].) Approximately 5 gal of water or 3 gal of diesel oil/acre (47.5 liters water or 28.5 liters diesel/ha) will provide an adequate carrier. Although some range managers prefer diesel oil, it is doubtful that any increase in effectiveness justifies the additional cost. In dense stands of sagebrush, a greater volume of spray material may be needed to insure proper coverage. Low rabbitbrush (*Chrysothamnus viscidiflorus*), lanceleaf rabbitbrush (*C. viscidiflorus* ssp. *lanceolatus*), and broom snakeweed (*Gutierrezia sarothrae*) can be killed along with sagebrush by increasing the application rate of 2,4-D to 3 lb/acre (3.4 kg/ha) and spraying during the latter part of the effective season for killing sagebrush (Eckert and Evans 1968; Laycock and Phillips 1968; Pechanec and others 1965).

Application of the spray solution can be made with ground rigs, fixed-wing aircraft, or helicopters. Use of ground equipment is limited to relatively level, rock-free areas, whereas airplanes and helicopters can apply the herbicide to nearly all sites. Helicopters allow safe, low-level flying at reduced speeds and permit precise application to designated areas. Spraying should be accomplished when winds are less than 8 mi/h (13 km/h) and temperature is below 70° F (21° C). Such conditions normally occur in early morning and reduce the problems associated with evaporation, volatilization, drift, and air turbulence.

Because of the effects of 2,4-D on species associated with sagebrush, composition of the vegetation must be carefully considered. Perennial grasses are seldom damaged, so they can be expected to increase as a result of reduced competition from sagebrush. However, many desirable perennial forbs and shrubs are severely damaged by spraying, and this damage must be evaluated in relation to anticipated benefits.

Some forbs are particularly vulnerable to 2,4-D, but effects have been largely ignored by many range scientists in their efforts to increase production of grass. Nevertheless, effects on forbs of spraying with 2,4-D have been observed in Idaho (Blaisdell and Mueggler 1956a), Nevada (Eckert and others 1972; Laycock and Phillips 1968), Oregon (Miller and others 1980), and Wyoming (Hurd 1955). Evaluation of response in Idaho has been expanded to include observations from the other States (table 2). Consistency of results for the various situations lends confidence to the assigned damage ratings.

Among those forbs moderately or severely damaged by spraying are such important forage species as arrowleaf balsamroot (*Balsamorhiza sagittata*), milkvetch (*Astragalus stenophyllus*), one flower sunflower (*Helianthella uniflora*), several lupines (*Lupinus* spp.), and bluebell (*Mertensia oblongifolia*). Important forage plants not seriously damaged by 2,4-D include hawksbeard (*Crepis acuminata*), geranium (*Geranium viscosissimum*), penstemon (*Penstemon radicosus*), and groundsel (*Senecio integerrimus*). Groundsel, however, is a species that matures and dries early in the growing season, and it might be damaged by early spraying. Such poisonous species as deathcamas (*Zygadenus paniculatus*), halogeton (*Halogeton glomeratus*), and orange sneezeweed (*Halenium hoopesii*) are severely damaged by 2,4-D, whereas larkspurs (*Delphinium depauperatum* and *D. glaucescens*) are unharmed by spraying rates normally used for sagebrush control.

**Table 2.**—Mortality[1] of forms on areas sprayed with 2,4-D to control big sagebrush (largely from Blaisdell and Mueggler 1956)

| Species | Mortality | Species | Mortality |
|---|---|---|---|
| *Achillea millefolium* | Unharmed | *Galium boreale* | Unharmed |
| *Agastache urticifolia* | Light | *Geum triflorum* | Heavy |
| *Agoseris* ssp. | Moderate | *Geranium viscossissimum* | Unharmed |
| *Antennaria microphylla* | Light | *Helianthella uniflora* | Heavy |
| *Aplopappus* sp. | Unharmed | *Linum lewisii* | Unharmed |
| *Arenaria congesta* | Unharmed | *Lithospermum ruderale* | Moderate |
| *Arnica fulgens* | Light | *Lupinus caudatus* | Heavy |
| *Aster foliaceus* | Unharmed | *Lupinus laxiflorus* | Heavy |
| *Aster scopulorum* | Moderate | *Lupinus leucophyllus* | Moderate |
| *Astragalus convallarius* | Unharmed | *Lupinus sericeus* | Heavy |
| *Astragalus miser praeteritus* | Unharmed | *Mertensia oblongifolia* | Heavy |
| *Astragalus salinus* | Unhar,ed | *Opuntia polyacantha* | Unharmed |
| *Astragalus stenophyllus* | Heavy | *Penstemon radicosus* | Light |
| *Balsamorhiza sagittata* | Heavy | *Penstemon* spp. | Heavy |
| *Calochortus macrocarpus* | Unharmed | *Perideridia gairdneri* | Unharmed |
| *Castilleja* spp. | Heavy | *Phlox canescens* | Light |
| *Comandra umbellata* | Light | *Potentilla gracilis* | Heavy |
| *Crepis acuminata* | Unharmed | *Potentilla* spp. | Heavy |
| *Delphinium depauperatum* | Unharmed | *Rumex* sp. | Unharmed |
| *Delphinium glaucescens* | Unharmed | *Senecio integerriumus* | Light |
| *Erigeron corymbosus* | Light | *Solidago* sp. | Unharmed |
| *Eriogonum heracleoides* | Light | *Trifolium macrocephalum* | Heavy |
| *Eriogonum ovalifolium* | Unharmed | *Viola* spp. | Unharmed |
| | | *Zigadenus paniculatus* | Heavy |

[1]Ratings: unharmed; light, 1 to 33 percent kill; moderate, 34 to 66 percent kill; heavy, 67 to 100 percent kill.

Temporary damage to shrubs by spraying is often severe. Aerial portions of snowbrush (*Ceanothus velutinus*), downy rabbitbrush (*Chrysothamnus viscidiflorus* ssp. *puberulus*), aspen (*Populus tremuloides*), chokecherry (*Prunus virginiana*), snowberry (*Symphoricarpos oreophilus*), and willows are easily damaged by 2,4-D. Although these species sprout vigorously, production of herbage and seed is greatly reduced for several years. As with burning, serviceberry (*Amelanchier alnifolia*) is severely damaged by spraying because little sprouting occurs, and, therefore, reestablishment of this desirable species may be extremely slow. Bitterbrush (*Purshia tridentata*), a valuable forage species for both livestock and big game, is apparently resistant to spraying provided the stand is mature. Young plants, however, are especially susceptible to 2,4-D, according to Hyder and Sneva (1962). These investigators observed considerable mortality in bitterbrush following spraying for sagebrush control, but concluded that damage is minimal when spraying occurs during the period between appearance of new leaves and initiation of twig elongation and flowering. Sagebrush will be killed effectively during this period. Shrubby cinquefoil (*Potentilla fruiticosa*), pricklypear (*Opuntia polycantha*), and horsebrush (*Tetradymia canescens* var. *inermis*) are apparently unharmed by 2,4-D.

The differences in response of various associated forbs and shrubs indicate a need for careful consideration of vegetal composition when planning range improvement by spraying with 2,4-D to control sagebrush. Indiscriminate spraying may destroy many desirable species and allow their replacement by inferior species not damaged by 2,4-D, or by invasion of undesirable annuals. In such cases, seeding may be necessary to insure satisfactory results. Also, total forage production may be decreased for several years. This is especially probable on sheep ranges where forbs supply a large part of the forage, on big-game ranges where tops of shrubs are killed, or on sage grouse (*Centrocercus urophasianus*) habitat where sagebrush and forbs supply a major portion of their diet.

Managers should know the improvement potential of ranges they plan to treat; consequently, they must recognize habitat types or range sites and relative condition. This is essential because the greatest response to sagebrush control will usually occur on high-potential sites in fair condition, where a well-distributed stand of grass can increase and replace the sagebrush. Productive potential of dwarf sagebrush habitat types is seldom great enough to justify sagebrush control. Similarly, expected improvement in very poor condition habitat types of big sagebrush does not justify spraying unless seeding is undertaken to insure and hasten the recovery process.

Usually, erosion hazard is not increased by spraying. The dead standing brush, undisturbed soil and litter cover, and increased density and vigor of perennial grasses all contribute to soil stability and favorable hydrological conditions. Furthermore, stream contamination from 2,4-D is negligible if the spray is carefully applied and buffer strips approximately 100 ft (30 m) wide bordering the stream channel are left unsprayed (Schroeder and Sturges 1980).

In order to allow desirable perennials the opportunity to take advantage of reduced sagebrush competition, sprayed ranges should be rested for at least the balance of the year in which they are sprayed. Depending on range condition, species composition, and other circumstances, it may be desirable to protect the sprayed area from grazing until after seed dissemination the following year. Improvement will probably be enhanced by a conservative level of stocking.

## MECHANICAL REMOVAL

Several mechanical methods for sagebrush control have been successfully used during the past 50 years. These include plowing or disking, root cutting, beating or shredding, railing, and chaining (Pechanec and others 1965; Plummer and others 1968; Parker 1979). Choice among these methods will depend upon such factors as size and density of the sagebrush, need to destroy or preserve understory vegetation, size of area to be treated, rockiness and other characteristics of the site, and availability of equipment.

### Plowing or Disking

Where there is not an adequate understory of desirable perennials, plowing or disking will destroy the sagebrush and prepare a good seedbed for revegetation. The most effective implements are the wheatland plow, offset disk, and brushland plow. The latter has been most popular, particularly on rocky areas, because pairs of disks are independently spring-controlled so that they can rise over obstructions without excessive breakage. Plowing to a depth of a few inches should be sufficient.

Several types of root-cutting equipment are available commercially. A common design consists of one or more V-shaped blades mounted on a heavy frame. When these are pulled through the soil at 4 or 5 inches (10 or 12 cm) deep, most of the vegetation is killed, but disturbance to the soil surface is minimal. This treatment may not provide as good a seedbed as disking, but the erosion hazard is less. Root cutting must be confined to relatively rock-free areas or breakage may be excessive. Seeding is necessary to restore a satisfactory stand of desirable species.

### Beating or Shredding

A wide variety of mechanical equipment has been developed to destroy the aboveground portions of plants by cutting, beating, or shredding and leaving a coarse layer of litter on the ground surface. Although such treatments can generally be effective for sagebrush control, cost is relatively high because the heavy equipment required is expensive to buy and operate. Rocks or other obstructions will cause excessive breakage. Herbaceous vegetation suffers only minimal damage, so it can immediately take advantage of reduced competition. This treatment may miss or cause little damage to small sagebrush plants, and such undesirable shrubs as rabbitbrush and horsebrush will sprout profusely.

### Railing

Uprooting or breaking off sagebrush by dragging a heavy rail across the stand is one of the oldest methods of control. It was originally used to clear lands for farming, but has been successfully used on many range areas. Railing is particularly effective on level, rock-free sites where the sagebrush is large and brittle. As with shredding, kill of small sagebrush plants or sprouting shrubs is poor. Damage to understory grasses and forbs is slight.

### Chaining

Anchor chaining is an effective, economical, and widely applicable method for thinning stands of big sagebrush and releasing grasses and forbs. It was originally developed for eliminating stands of pinyon and juniper, but has also been used successfully for controlling many other woody species. Chains about 200 ft (60 m) in length, with links weighing between 25 and 90 lb (11 and 40 kg) each, are pulled between two tractors. This will create a swath about 100 ft (30 m) wide. Chaining is adapted to varied terrain and is especially useful on areas too rocky or steep for other mechanical methods.

If an adequate understory is not present, a modified chain may be used to prepare a good seedbed. This is accomplished by constructing a chain with 18-inch (45-cm) lengths of light rail welded to each link. This type of chain will destroy more sagebrush and will also allow covering of introduced seed. Normally, twice-over chaining in opposite directions, with broadcast seeding between the two chainings, will produce desired results.

### General Considerations

Although mechanical sagebrush control and revegetation may be successfully carried out on some low and alkali sagebrush habitat types, such measures should generally be avoided on dwarf sagebrush sites. These normally are areas of shallow soils with low productive potential, and satisfactory revegetation is often difficult to achieve. Furthermore, this existing stand of sagebrush is often of considerable value to wildlife.

On areas where control is in effect, management should encourage continued maximum production of forage for livestock and wildlife consistent with soil protection. Grazing use should be designed to discourage the return of sagebrush, and thus avoid the need for frequent control measures. As with burning and spraying, best results are obtained from mechanical sagebrush control if sufficient protection from grazing is provided to allow residual or seeded grasses and forbs to take advantage of the reduced competition. No grazing should be allowed for at least a year after treatment, and on seeded areas, protection should be continued for two growing seasons to allow establishment of the new plants.

## BIOLOGICAL CONTROL

Control of pricklypear (*Opuntia stricta* and *O. inermis*) in Australia by the phycitid moth (*Cactoblastis cactorum*) introduced from South America, and control of St. Johnswort (*Hypericum perforatum*) in the western United States by the European chrysomelid (*Chrysolina gemellata*) are outstanding examples of biological control of undesirable plants (Huffaker 1957). These and other successes in this field offer some hope that sagebrush may similarly be controlled by biological agents. As with burning, spraying, and mechanical removal of sagebrush, the aim of biological control is not eradication but reduction to a tolerable level. Insects, small mammals, and large herbivores are all possibilities for biological control of sagebrush. Although these control agents hold considerable promise for the future, much research and testing will be necessary before practical use can be recommended.

### Insects

Although a wide variety of insects inhabit sagebrush-grass communities, only a few have caused significant damage to sagebrush. One of these is a moth (*Aroga websteri*) whose larvae feed exclusively on foliage of big sagebrush and such related species as low, black, and silver sagebrushes. Gates (1964) reported that in Oregon during 1962, most of the sagebrush on 10,000 to 15,000 acres (4 000 to 6 000 ha) was killed by this insect, and during the following year some 12 million acres (5 million ha) were infested. Degree of infestation and effects on the sagebrush are highly variable; however, young, vigorous stands on productive sites seem to be most resistant. Apparently, *Aroga* populations are controlled by parasites and do not remain at peak levels for more than a year to two.

A leaf-feeding beetle (*Trirhabda pilosa*) appears to have a high potential for killing sagebrush, but few outbreaks have been noted. Severe damage by this insect to big sagebrush in British Columbia was observed by Pringle (1960) during 1956-58, but the high infestation was short-lived. A similar infestation of *Trirhabda attenuata* on threetip sagebrush in Wyoming was reported by Fisser and Lavigne (1961).

The insects discussed above are native to sagebrush-grass vegetation. Apparently, an ecological balance is maintained in which damage to the sagebrush is minimal. However, when insect population explosions are periodically triggered by favorable environmental factors, sagebrush can be severely damaged. The result is similar to that caused by natural fires. Although sagebrush may be destroyed on sizable areas, it eventually becomes reestablished on sites to which it is adapted. In any event, it seems futile to attempt biological control of sagebrush with these insects until more is known about their population dynamics, especially triggering mechanisms.

#### Small Mammals

Like insects, numerous small mammals are native to sagebrush-grass ranges. For the most part, they have not caused serious damage to sagebrush. However, voles (*Microtus* spp.) are known to girdle and kill sagebrush over sizable areas. Mueggler (1967) observed an outbreak of voles during 1962-64 in southwestern Montana, which caused damage to a number of shrubs including big and silver sagebrush, sumac (*Rhus trilobata*), bitterbrush, mountain mahogany (*Cercocarpus ledifolius*), and serviceberry (*Amelanchier alnifolia*). Sagebrush was severely damaged by bark stripping, and more than 80 percent of the stand was killed in some areas. A similar population explosion of longtailed voles (*Microtus longicaudus*) in 1969 caused considerable mortality to big sagebrush over extensive areas in Utah (Frischknecht and Baker 1972). Highest kills of sagebrush occurred on areas where herbaceous vegetation was thick and a snow cover persisted throughout the winter.

Although voles are capable of thinning or destroying stands of sagebrush, sufficient information is not available to allow their use for biological control. They are natives of the sagebrush-grass ecosystem, and normal populations apparently have little impact. Factors responsible for population eruptions and methods of inducing them will have to be known before voles or other small mammals can be effectively managed for biological control of sagebrush.

#### Large Herbivores

During severe winters, stands of sagebrush have been decimated by high concentrations of deer and elk. Likewise, domestic livestock have destroyed sagebrush on heavily used areas near waterholes, salt grounds, and winter feedyards. However, control of sagebrush on large range areas by such concentrated use is neither possible nor desirable.

The most successful control of sagebrush by large herbivores has been with sheep. At the U.S. Sheep Experiment Station in eastern Idaho, heavy late-fall grazing by sheep improved poor-condition range by reducing threetip sagebrush some 20 percent and allowing a 30 percent increase in grasses and forbs (Laycock 1967). In central Utah, late-fall and winter grazing of crested wheatgrass pastures with sheep reduced the size of big sagebrush plants and limited their reproduction (Frischknecht and Harris 1973).

To date, only grazing of sheep during the late fall or winter has shown significant promise for biological control of sagebrush. Grazing by goats is another possibility, but it has not been adequately tested. For the most part, biological control of sagebrush is not a practical substitute for burning, spraying, or mechanical removal at the present time.

#### Frequency of Control Measures

Because reestablishment of sagebrush is hindered by competition from other species, management following control should attempt to create and maintain a good stand of perennial grasses and forbs. Ranges in poor condition should usually be seeded to desirable species and all should be grazed conservatively. However, long-term studies on sagebrush control by burning (Harniss and Murray 1973) and chemicals (Sneva 1972) indicate that brush will eventually return to big sagebrush habitat types regardless of management. Consequently, there will be a need for planning sagebrush control on a continuing basis, especially in mountain big sagebrush habitat types. In addition to competing vegetation and grazing practices, the length of time between control measures is influenced by undefined weather variables (perhaps moisture patterns) that favor sagebrush seedling survival and establishment. Seed production of sagebrush before and after control may also be a factor in rapidity of its reestablishment.

At any rate, control measures such as burning or spraying apparently do not have serious long-term impacts on either vegetation or soil. If necessary, sagebrush control at 20-year intervals should be tolerable for most situations.

## Revegetation

Vegetation on extensive areas of sagebrush-grass range has been depleted by past abuses. Where original cover of perennial grasses and forbs has been mostly destroyed, sagebrush and other shrubs with low palatability have increased, and often such undesirable annuals as cheatgrass, halogeton, and medusahead have invaded. In such situations neither complete protection nor conservative grazing can restore a desirable vegetal cover within a reasonable period because a seed source of desirable species is lacking and competition from the undesirable plants is severe. For example, Holmgren (1976) observed little or no improvement in depleted sagebrush-grass vegetation on several sites in Nevada after 38 years of protection or continued grazing. Consequently, removing competing vegetation, especially sagebrush, and seeding with desirable species of grasses, forbs, and shrubs is often the only satisfactory method of restoration.

Much has been learned about seeding western rangelands during the past 50 years, and useful guides were provided by Plummer and others (1955) on where, how, when, and what to seed, as well as proper management of seeded ranges. Keller (1979) synthesized similar information in a comprehensive literature review for the sagebrush-grass ecosystem. He emphasized selection of adapted species and proper methods including reduction of competition, seedbed preparation, application of seed, proper covering, and grazing management.

Hull (1974) reexamined 2,450 plots on depleted sagebrush rangelands in southern Idaho 20 to 40 years after seeding. Fairway and desert crested wheatgrasses (*Agropyron cristatum* and *A. desertorum*) were the most successful species on dry sites, whereas intermediate (*A. intermedium*) and pubescent (*A. tricophorum*) wheatgrasses were superior on the moist sites. Russian wildrye (*Elymus junceus*) was fairly well-adapted, especially to moderately saline soils. Western (*A. smithii*) and Siberian (*A. sibiricum*) wheatgrasses produced some good stands, but were not consistently successful. Other species exhibiting varying degrees of success were thickspike, tall, and bluebunch wheatgrasses (*A. dasystachyum*, *A. elongatum*, and *A. spicatum*), smooth brome (*Bromus inermis*), big, bulbous, and Sandberg bluegrasses (*Poa ampla, P. bulbosa*, and *P. sandbergii*), and arrowleaf balsamroot (*Balsamorhiza sagittata*). Control of competing vegetation and adequate covering of seed was necessary to obtain good stands.

In general, stands of adapted species are closely related to rate of seeding, although initial differences largely disappear with time. On the Upper Snake River Plains, Mueggler and Blaisdell (1955) compared five rates of seeding crested wheatgrass: 2, 4, 8, 12, and 24 lb/acre (2.2, 4.5, 9.0, 13.5, and 27.0 kg/ha). The three highest rates produced the best stands during the first 3 years, but after 6 years yield of all stands was similar. In other southern Idaho studies, Hull and Holmgren (1964) reported that after 10 years yields from plots seeded at rates varying from 1 to 40 lb/ acre (1.1 to 45.0 kg/ha) were approximately the same. In Utah, however, plots of crested and pubescent wheatgrass that were seeded lighter than 4 lb/acre (4.5 kg/ha) were not producing at full potential even after the ninth growing season (Cook and others 1967). For the most part, seeding wheatgrasses at the rate of about 8 lb/acre (9.0 kg/ha) should be adequate to produce a satisfactory stand within a reasonable length of time.

Most of the early effort in revegetation of sagebrush-grass ranges was oriented toward increasing quantity and quality of livestock forage and providing better watershed protection. Consequently, establishment of a good stand of palatable, perennial grass was the usual objective, and this often resulted in stands of crested or other exotic wheatgrasses. With the recognition of the limited value of single species and the risks involved from such factors as insects, disease, and drought, more and more attention was given to mixtures that would provide better wildlife habitat, improve esthetics, include legumes for nitrogen fixation, and provide better nutritional balance for both livestock and wildlife.

From about 1960, increasing emphasis has been placed on the use of shrubs in mixtures for range revegetation. Selection and propagation studies have demonstrated that a number of native and exotic species can be successfully established within most sagebrush-grass communities (Monsen and Christensen 1975). Species selected for their forage and cover values, productivity, adaptability, and ease of establishment include: antelope bitterbrush (*Purshia tridentata*), desert bitterbrush (*P. glandulosa*), Martin ceanothus (*Ceanothus martinii*), cliffrose (*Cowania mexicana*), blueberry elder (*Sambucus cerulea*), green ephedra (*Ephedra viridis*), rubber rabbitbrush (*Chrysothamnus nauseosus*), fourwing saltbush (*Atriplex canescens*), winterfat (*Ceratoides lanata*), and, of course, several sagebrushes. Considerable variability among separate collections, ecotypes, and subspecies has been observed, and these differences are being used by personnel of the Intermountain Station's Shrub Sciences Laboratory at Provo, Utah, to promote the development of superior traits. Already, the forage qualities of various shrubs have been markedly improved through selection and propagation of palatable and productive collections.

Sagebrushes are especially aggressive, productive, and persistent. Such plants are good candidates for improvement through increased forage yield and quality (Welch and McArthur 1979a). Sagebrushes vary in growth rate and form (McArthur and Welch 1982), in protein content (Welch and McArthur 1979b), and in other qualities. With these variations they make good material for genetic improvement through selection alone or selection combined with hybridization. Improvement in both forage value and soil-binding capability should be possible. Nevertheless, even the most improved sagebrush may fall short as livestock forage because of the grazing preferences of particular animals, especially cattle. Wise management of sagebrush-grass ranges, therefore, may entail maintaining productive natural sagebrush stands, seeding sagebrush, or eradicating it, depending upon the management objective (McArthur and Plummer 1978).

Although the work of Plummer and others (1968) was primarily directed at restoration of big-game ranges, their guidelines, which follow here, are appropriate for revegetation of almost all areas in the sagebrush-grass ecosystem being managed for multiple uses and values.

1. **Change in plant cover must be determined, by rational criteria, to be necessary and desirable.** The usual goal of developing a productive stand of desirable shrubs, grasses, and forbs can sometimes be achieved by selective plant control or change in grazing management. However, at least one desirable shrub and 10 desirable herbaceous plants per 100 $ft^2$ (9 $m^2$) should be present. Revegetation may be necessary to provide browse for winter or succulent forage for early spring. Watershed considerations are also important, and seeding grasses and forbs may be necessary for soil stabilization.

2. **Terrain and soil must be suitable for the selected restoration.** Deep, fertile soils on level to gently sloping land are preferred sites for seeding. Shallow, rocky, or infertile soils seldom justify expensive restoration measures. Excessive amounts of soluble salts often preclude successful revegetation. Treatment of steep slopes is difficult and expensive, and may not be worthwhile unless the need for erosion control is critical.

3. **Precipitation must be adequate to assure establishment and survival of planted species.** Average annual precipitation usually should be 10 inches (25 cm) or more if seeding is part of the restoration project. Where precipitation is near this limit, only the more drought-resistant species such as crested wheatgrass, Russian wildrye, bluestem wheatgrass, and dryland alfalfa should be seeded. Existing vegetation is a good indicator of the moisture situation.

4. **Competition from existing vegetation must be light enough to allow successful establishment of seeded species.** Thick stands of big sagebrush and annuals such as cheatgrass must be at least partially eliminated by some of the sagebrush control methods already discussed. Seeding directly into existing vegetation (interseeding) may also be practiced successfully if the drill is equipped with scalpers to clear a swath of sufficient width to decrease competition.

5. **Only adapted species and strains should be planted.** Species used for seeding must be able to establish and maintain a suitable stand of vegetation on the selected site. Probability of success will be increased by using species with demonstrated adaptability and seed from an environment similar to that of the area proposed for seeding.

6. **Mixtures of plant types rather than single species should be seeded.** Terrain and climatic factors are often variable. Seeding mixtures will offer the best chance of including suitable species for the diverse sites, and will usually result in a superior ground cover for control of erosion. Also, mixtures of grasses, forbs, and shrubs will better supply the nutritional needs of grazing animals. If seeds of certain species are in short supply, they can be hand-seeded on special sites to which they are best adapted.

7. **Sufficient seed of acceptable purity and viability should be seeded to insure a satisfactory stand.** Too heavy seeding is needlessly expensive, but skimping may jeopardize establishment of a good stand. Normally, 8 to 20 lb/acre (9.0 to 22.5 kg/ha) of the total seed mixture will be sufficient. Rates at the lower end of this scale are usually adequate for drilling, whereas the higher rates will be necessary if seed is broadcast. The required rate will also depend on species and quality of the seed. Good fill of recently collected seed is a good indicator of high quality if laboratory tests are not possible. Seeding rates should be increased if purity or viability is poor.

Dormancy of most seeds can be broken by stratification—subjecting them to temperatures between 32° and 40° F (0° and 4.4° C) for a period of 6 to 20 weeks in moist sand, peat moss, or newspaper. Dormancy will be naturally broken if seeds are planted in fall or winter. For some shrubs, treatment with thiourea or scarification with sulfuric acid or mechanical abrasion will help to overcome dormancy.

8. **Seed must be covered.** A light covering of soil, usually one-fourth to one-half inch (0.6 to 1.2 cm), will be sufficient. Drills can be set at the required depth, and chaining or pipe harrowing will usually provide adequate covering following broadcasting without burying the seed too deeply.

9. **Seeding or planting should be done in the season that promises best conditions for plant establishment.** Seeding is the usual means of establishing grasses, forbs, and a few shrubs. However, some shrubs can be propagated most satisfactorily by transplanting, usually in the spring. Direct seeding in late fall and throughout the winter, climate permitting, will usually be preferable for most species.

10. **Revegetated areas must be properly managed.** Livestock should be excluded until new plants are well established, and thereafter grazing should be regulated so that a vigorous stand can be maintained. Control may sometimes be necessary to prevent damage from big game. However, if treated areas are large, damaging concentrations will usually be avoided. Newly revegetated areas are also subject to damage from rabbits, rodents, and insects, but several effective control measures are available.

These general revegetation guides should be adapted to peculiar environments and specific objectives of areas selected for treatment. For revegetating a big sagebrush habitat type, Plummer and others (1968) recommend removal of sagebrush competition by anchor chaining, controlled burning, or spraying with 2,4-D. Seeding can be accomplished by aerial broadcasting or by using the rangeland drill. Anchor chaining is economical and effective for covering broadcast seed. If chaining is used as the method for sagebrush control, seed can be applied between the two chainings made in opposite directions. A suggested seed mixture for areas with approximately 10 inches (25 cm) annual precipitation includes the following:

| | *Lb/acre* | *kg/ha* |
|---|---|---|
| Fairway crested wheatgrass (*Agropyron cristum*) | 3.0 | 3.3 |
| Standard crested wheatgrass (*A. desertorum*) | 2.0 | 2.2 |
| Bluebunch wheatgrass (*A. spicatum*) | .5 | .6 |
| Bluestem wheatgrass (*A. smithii*) | .5 | .6 |
| Intermediate wheatgrass (*A. intermedium*) | .5 | .6 |
| Pubescent wheatgrass (*A. tricophorum*) | .5 | .6 |
| Russian wildrye (*Elymus junceus*) | 1.0 | 1.1 |
| Alfalfa-Rambler, Nomad, or Ladak (*Medicago sativa*) | 1.0 | 1.1 |
| Arrowleaf balsamroot (*Balsamorhiza sagittata*) | .5 | .6 |
| Fourwing saltbush (*Atriplex canescens*) | 1.0 | 1.1 |
| Rubber rabbitbrush (*Chrysothamnus nauseosus*) | .5 | .6 |
| Total | 11.0 | 12.4 |

For areas of higher precipitation such as habitat types of mountain big sagebrush, standard crested wheatgrass can be omitted, and Utah sweetvetch (*Hedysarum boreale* var. *utahensis*) and small burnet (*Sanguisorba minor*) can be added. Such shrubs as antelope bitterbrush, desert bitterbrush, cliffrose, Utah serviceberry (*Amelanchier utahensis*), and winterfat, can also be included in the mixture or seeded in special areas. Other grasses and forbs that may be substituted for herbaceous species in the mixture are bottlebrush squirreltail (*Sitanion hystrix*), Great Basin wildrye (*Elymus cinereus*), Indian ricegrass (*Oryzopsis hymenoides*), Siberian wheatgrass (*Agropyron sibericum*), Lewis flax (*Linum lewisii*), sicklepod milkvetch (*Astragalus cicer*), and yellow sweetclover (*Melilotus officinalis*). Improved varieties of many of these species have been developed and should be used where appropriate.

In southern Idaho, Monsen (1981, unpublished manuscript) drilled many of the above species into a depleted alkali sagebrush (*Artemisia longiloba*) Idaho fescue (*Festuca idahoensis*) habitat type of untreated areas as well as those on which sagebrush was controlled by burning and chaining. Good stands resulted from a mixture of slender (*Agropyron trachycaulum*), crested, and intermediate wheatgrasses, Russian wildrye, alfalfa, Lewis flax, and small burnet on burned and chained areas. But failures resulted from drilling directly into untreated stands of sagebrush.

Because of the wide variation in sagebrush sites needing revegetation, soil and climatic factors should be considered before restoration is attempted so that allowances can be made for peculiar conditions. And because natural vegetation is a reliable integrator of environmental factors, classification by habitat types provides a useful tool for evaluating site potential, formulating adequate prescriptions, and extrapolating successful experiences from one area to another.

## Grazing

### INTENSITY AND SEASON

Although the influence of grazing may be exerted in many ways—trampling, fertilizing the soil, disseminating and planting seed—the most obvious influence is that of reducing the volume of herbage and the area of photosynthetic surface (Ellison 1960). Because of this, many studies have attempted to evaluate the influence of grazing by clipping herbage to various degrees at different times during the growing season. Although clipping does not simulate grazing exactly, it can be a useful tool when applied with judgment in connection with studies of actual grazing.

Bluebunch wheatgrass (*Agropyron spicatum*), an important forage plant on many western ranges, has received considerable attention. Hanson and Stoddart (1940) observed that heavily grazed plants of bluebunch wheatgrass were smaller, produced fewer seeds, and had a markedly reduced root system. Stoddart (1946), in a study on this species in northern Utah, reported that severe clipping to heights of 1 and 2 inches (2.5 and 5.0 cm) reduced yield the following year and, except for very early spring and fall clipping, caused high mortality. In Montana, McIlvanie (1942) showed that repeated close clipping during active growth strongly reduced carbohydrate storage in the roots and stem bases of bluebunch wheatgrass. Also in Montana, Heady (1950) concluded that clipping this grass only once to 6 inches (15 cm) at the flowering stage would not allow its maintenance. In further studies with this species on the Snake River Plains of eastern Idaho, Blaisdell and Pechanec (1949) reported that clipping to ground level at any date, except after dormancy in the fall, reduced leaf height, flower stalk numbers, and herbage production the following year. Arrowleaf balsamroot (*Balsamorhiza sagittata*) exhibited a similar but less marked response—perhaps because stored foods were less severely depleted in this forb's large taproot. With both species, flower stalk production was the most sensitive criterion of injury. These results clearly show the importance of season: defoliations are most injurious at the time growth is well-advanced in the spring, root reserves have been expended, and substantial regrowth during the dry summer is impossible.

From a review of these and similar studies with other species, Ellison (1960) concluded that the usual effect of grazing certain species in a community is to handicap them while encouraging others. Therefore, under range conditions, the effect of selective grazing is commonly a reduction in relative amount of palatable species. Such changes in vegetation are roughly proportional to grazing intensity, being most pronounced under severe utilization. Some observations suggest that forage plants respond as well under light grazing as no grazing. However, other studies show injurious effects even at light intensities (Johnson 1956).

Despite the evidence that herbage removal is usually harmful to the plant, it has been demonstrated by research and experience that range improvement or maintenance can often be achieved by careful grazing management. Consequently, grazing sagebrush-grass range with domestic livestock can be a productive use and at the same time a means of manipulating the vegetation—for either better or worse. Since most grasses and forbs are more palatable to livestock than are shrubs, especially during the growing season, the tendency is for sagebrush and other shrubs to flourish at the expense of herbaceous species. However, properly regulated grazing can be compatible with a desirable mixture of vegetation and with other uses and values of the ranges.

Since reaction to grazing varies with composition and condition of the vegetation, intensity and season of use, kind of livestock, and husbandry practices, knowledge of these factors can be used to minimize impacts. For example, sagebrush-grass range in fair condition may be improved by a particular grazing regimen, but similar improvement of a depleted or poor condition range will probably be impossible because of the paucity of desirable herbaceous species and competition from a thick stand of sagebrush. Heavy utilization may not be particularly injurious during certain seasons when the plant is dormant or when it has adequate opportunity for regrowth, whereas lighter use at other times can be extremely injurious and override effects of favorable practices. Different kinds of livestock have different preferences for forage, and these may vary with season of grazing. Uniform livestock distribution and accompanying forage utilization can be encouraged by such simple measures as proper placement of salt, adequate watering facilities, riding or herding, and fencing—without the use of special grazing systems. As a matter of fact, the need for special systems is intensified by the failure to apply this basic husbandry.

## GRAZING SYSTEMS

Driscoll (1967) described five common grazing systems, and all have been used on sagebrush-grass ranges:

1. **Continuous.**—Livestock are allowed free access to any part of a range throughout the grazing season, which may be either seasonal or yearlong. Use follows the same general pattern each year.
2. **Rotation or alternate.**—The orderly alternation, both within and between years, in the grazing use of two or more portions of the range to avoid grazing the same unit at the same time each year, but without specific regard for plant reproduction. The system is designed to promote plant vigor.
3. **Deferred.**—The delay of grazing during the growing season to promote seed production and plant reproduction, and to restore or maintain vigor of existing vegetation.
4. **Rotation-deferred.**—Rotating the deferment of two or more range units to promote plant reproduction and improve vigor. Grazing is normally allowed on all units of the range allotment for at least part of each grazing season.
5. **Rest-rotation.**—Refinement and combination of the deferred and rotation grazing systems so that complete rest will be allowed on parts of the range each year or grazing season to promote restoration of plant vigor and reproduction.

Vallentine (1979) provided a concise review of grazing systems applied to sagebrush-grass range. Pertinent information from his review and other sources is summarized in the following paragraphs.

Pechanec and Stewart (1949) recommended both rotation grazing and spring deferment for threetip and mountain big sagebrush habitat types grazed by sheep in spring and fall. They concluded that rotating grazing among different units in the spring, but in a different sequence each year, was an effective method of maintaining range in satisfactory condition or improving range in unsatisfactory condition. A further recommendation was that one unit each year be deferred until fall, and that some leeway and good judgment be used in adapting to climatically induced plant growth variations from year to year.

In southeastern Oregon on sagebrush-grass range dominated by big sagebrush, bluebunch wheatgrass, Idaho fescue, and Sandberg bluegrass, Hyder and Sawyer (1951) concluded that season-long grazing was more favorable to both cattle and vegetation, mainly because the rotation system resulted in serious overgrazing during the first period of use. On a big sagebrush-wheatgrass range in southern Wyoming, Gibbens and Fisser (1975) compared four-pasture rest-rotation, two-pasture deferred, and one-pasture continuous systems grazed by cattle from spring until winter. Following a 25 percent reduction in permitted grazing at the beginning of the study, all units improved in range conditions without apparent effect on wildlife populations. Apparently stocking rates had not put enough stress on vegetation to cause differences, because range conditions improved under all treatments.

From studies with sheep in the threetip sagebrush/bluebunch wheatgrass habitat type at the U.S. Sheep Experiment Station near Dubois, Idaho, Laycock (1962) concluded that damage from heavy grazing is increased by early and continuous spring-long use and by grazing the same area during the same part of the spring season each year. He noted that grazing at the heaviest rate under spring rotation did not damage the range. Apparently, rotation grazing is necessary in the spring but not in the fall. From studies in the same vegetation type, Mueggler (1950) reported that an area in good condition was maintained over 25 years by heavy sheep grazing in the fall, whereas much lighter use in the spring caused serious deterioration (fig. 11). In a followup study, Laycock (1967) showed that both heavy fall grazing and complete protection improved poor condition range. In further studies Harniss and Wright (1982), after defining moderate grazing in the spring as 16 sheep days/acre (40 sheep days/ha), concluded that sheep can graze at the rate of about 36 sheep days/acre (90 sheep days/ha) in the summer without apparent damage to the vegetation, and that in the fall 60 sheep days/acre (150 sheep days/ha) can be grazed with a beneficial effect on the vegetation.

**Figure 11.—Poor-condition range on the left as a result of high intensity spring grazing by sheep contrasted with excellent-condition range on the right maintained by heavy fall use. Note the difference in production of grasses and forbs. This is an *Artemisia tripartita* ssp. *tripartita*/*Agropyron spicatum* habitat type at the U.S. Sheep Experiment Station.**

From a study on the Bighorn National Forest in Wyoming, Smith and others (1967) reported that in an Idaho fescue community with some inclusions of mountain big sagebrush, there was no evidence that rotation grazing was better than season-long grazing. They concluded that grazing intensity had more effect on animal production than did systems of grazing. In the Bighorn Basin after 8 years of different grazing treatments— including generally lighter grazing intensities and deferment in some years—range dominated by big sagebrush was largely taken over by wheatgrasses (Cooper 1953). That these striking changes occurred within so short a time suggests that the pristine vegetation of the area was grass, not shrubs, and that sagebrush was an invader whose position of dominance was maintained only as long as the grasses were suppressed by overgrazing.

On native mountain big sagebrush-grass range on the Ashley National Forest in eastern Utah, a comparison of summer-long grazing by cattle every year, summer-long in alternate years, and three-unit rest-rotation systems revealed no differences in cover, yield, or species composition of vegetation after 7 years (Laycock and Conrad 1980). Average daily gains of cattle over the entire period were similar for all systems. All areas were in fair to good condition and were grazed at a moderate intensity.

Rest-rotation grazing (Hormay and Talbot 1961), designed for management of perennial bunchgrass ranges, was originally tested at Harvey Valley in northern California on ranges that included big, low, and silver sagebrush types, as well as open grassland. After analyzing data from a five-pasture system grazed by cattle over 12 years, Ratliff and others (1972) concluded that rest-rotation grazing was superior to season-long grazing. However, Ratliff and Reppert (1974) reported that continuous grazing was more effective in controlling competing vegetation than it was damaging to Idaho fescue, and that vigor of this grass was not reduced by continuous grazing nor improved by full-season rest. From studies in the sagebrush type on the Arizona strip, Hughes (1980) concluded that rest-rotation and deferred grazing systems are a waste of money unless plant control treatments are applied to maintain an open stand of sagebrush. Grazing systems increase vigor of grasses but do not slow sagebrush reinvasion. Similarly, from observations in Nevada, Young and others (1979) reported that rest-rotation grazing is a useful system for sagebrush-grass range in fair to high condition, but for degraded ranges with overabundance of brush and little or no seed source for perennial grasses, rest-rotation as a technique for range improvement is little more than wishful thinking.

Mueggler (1972) pointed out that a problem may have been created by extending rest-rotation grazing to all types of range. Logic indicates that this grazing system has a better chance of succeeding on grasslands, where most of the vegetation is fairly palatable, than on ranges, where unpalatable species such as sagebrush and wyethia are prominent components of the stand and can take advantage of reduced competition. In any event, it seems necessary to balance desirable effects of heavy use, often associated with rest-rotation grazing, against undesirable effects on wildlife habitat, watershed protection, esthetics, and livestock weights.

Recent observations by the senior author on the BLM Pleasantview cattle allotment in southeastern Idaho indicate variable results from a three-unit rest-rotation system that has been in operation for approximately 10 years. Vegetation is largely mountain big sagebrush-grass with patches of aspen, chokecherry, or coniferous trees in canyon bottoms or on north-facing slopes. Fair-condition sagebrush-grass areas on moderate to steep slopes appear to be receiving light or moderate use and trend is upward (fig 12). This situation, which occurs on the major part of the allotment, has apparently improved general watershed conditions as banks of gullies and deeply eroded stream channels are showing substantial healing from sloughing and natural revegetation (fig 13). On the other hand, many of the more gentle slopes in the sagebrush-grass type are in poor condition with a thick stand of sagebrush and scarcely any understory of desirable grasses and forbs (fig. 14). Such areas exhibit no

Figure 12.—Fair-condition mountain big sagebrush-grass range on moderate slopes of the Pleasantview cattle allotment in southeastern Idaho. Apparently, forage utilization is not excessive and trend is upward.

Figure 13.—Apparent healing of a gully on the Pleasantview allotment as a result of bank sloughing and natural revegetation.

Figure 14.—Poor-condition range on a gentle slope in the Pleasantview allotment. Vegetation is a thick stand of mountain big sagebrush with an understory of annual weeds. There is no evidence of an upward trend.

Figure 15.—Depleted range within and adjacent to an aspen grove on the Pleasantview allotment. No improvement can be expected under such heavy use by cattle.

evidence of an upward trend. Likewise, other areas where cattle naturally congregate—canyon bottoms, around water developments, and aspen or chokecherry groves used for shading-up—are often in depleted or poor condition and show no evidence of improvement (fig. 15). Despite the generally satisfactory condition of much of sagebrush-grass type on the Pleasantview allotment, abuse of certain readily accessible parts of the range should not be tolerated.

Although rest-rotation grazing has been widely accepted as a panacea for range management problems, data are not available to demonstrate its real worth or to sort out the contribution of such important factors as plant control, revegetation, water development, fencing, and removal of trespass livestock—all of which have accompanied the application of rest-rotation grazing on Federal ranges. Certainly, there is no conclusive proof that rest-rotation is more effective than other systems on most sagebrush-grass ranges.

A common goal of all systems should be reduction of harmful effects of grazing while promoting beneficial effects, and many systems appear equally effective. Various combinations of rotation and deferment, as well as continuous grazing, have all proven to be successful where such factors as range condition, kind of livestock, stocking rate, season, and intensity were given proper consideration.

## OTHER CONSIDERATIONS

Rate of stocking—balancing numbers of grazing animals with forage resources—is the most important part of good grazing management (Pechanec 1956). Initially, the best estimate of grazing capacity that can be made should be accomplished through one of three methods: (1) examining past stocking records and relating them to current range condition and trend; (2) determining the stocking rate that has been used on a similar range, which is now in satisfactory condition; and (3) utilizing a current range inventory. The latter, however, may provide an unreliable estimate. For the most part, ranges are by their nature too variable to allow uniform treatment or response. Furthermore, variations in kind or class of livestock, in attention given by herders or riders, in seasonal and annual plant growth, and in impacts of wildlife and range pests, all work against successful computation of grazing capacity. Consequently, actual grazing with continuing evaluation of range and livestock performance is necessary, and precise determination of grazing capacity by other means should not be attempted.

Moderate utilization (no more than 50 percent herbage removal) of desirable forage species is necessary for adequate food synthesis and storage, maintenance of plant vigor, and completion of reproductive processes when grazing occurs during the growing season. Although heavier use may be possible when plants are dormant or if grazing is rotated, rested, or deferred to allow the forage plant to complete its life processes, such use should be applied with caution. Seemingly, there has been overoptimism in judging grazing capacity and allowable use, which has been an important factor in range deterioration. Sagebrush-grass vegetation often occurs on shallow, unstable soils, and in semiarid areas where droughts are frequent and conditions are only rarely favorable for seed production and seedling establishment. At any rate, it has become increasingly apparent that former utilization standards are often several times more than can be tolerated continuously, and that reduction in livestock numbers is often necessary to correct unsatisfactory conditions.

Range condition is especially important in the development of satisfactory management prescriptions for sagebrush-grass ranges. Depleted and poor condition ranges will respond slowly to even the best grazing management because pressure is kept on the already sparse stand of desirable grasses and forbs by grazing animals and by competition from sagebrush and other unpalatable species. Where such serious deterioration has occurred, control of unwanted species and revegetation with desirables is usually necessary. However, proper grazing practices will usually allow improvement of fair condition ranges or maintenance of those already in good or excellent condition.

Kind of livestock is another important influence. Cattle tend to graze the grasses most heavily, whereas sheep exhibit a preference for forbs. On overgrazed cattle ranges, forbs may increase initially as grasses are killed out. With continued grazing pressure, the more palatable forbs also disappear and sagebrush increases its dominance. On overgrazed sheep ranges, the palatable forbs are the first to disappear, followed by the fine bunchgrasses; sagebrush and other unpalatable shrubs take up the slack. Rotation of use between cattle and sheep can prove beneficial, especially to fair and good condition sagebrush-grass ranges.

Date at which grazing starts in the spring also can have major effects on forage and livestock production. Grazing too early may seriously damage desirable grasses and forbs that depend on stored food for growth. Early grazing can also compact the wet soil and physically damage plants, especially seedlings, and provide inadequate forage for livestock (Pechanec 1956). On sagebrush-grass ranges used by ewes and lambs, grazing can start when bluebunch wheatgrass leaves average 2.5 inches (6 cm) and soil is firm (Pechanec and Stewart 1949). This criterion, however, was established under a rotation system where sheep were only grazed for a couple of weeks before being moved to a new unit. Where grazing is continuous through the growing season, 4 to 6 inches (10 to 15 cm) initial growth may be required before the range is ready for grazing. Variations from year to year in early spring temperatures cause wide differences in date of range readiness. On the Upper Snake River Plains of Idaho over 23 years, there was a month's difference between earliest and latest dates. However, Blaisdell (1958) determined that the date of range readiness could be predicted with suitable accuracy from the mean temperature of March. The regression equation is: $Y = 65.86 - 1.39X$, in which Y is the number of days after March 31 and X is March mean temperature. In 2 out of 3 years, the actual date at which the range is ready for grazing will be within about 6 days of the date predicted.

Apparently, there are many ways to reach the desired objectives, and flexibility should not only be allowed but encouraged. Admittedly, uniformity in opening and closing the grazing season, in allowable utilization, in kind or class of livestock, in methods of salting, or in type of grazing system makes for easier administration of public rangeland, but it does not necessarily mean the best management. Early grazing can be tolerated and may be desirable if livestock are removed in time to allow adequate regrowth; heavy use can be allowed if sufficient rest is subsequently provided; change in season can be a useful management tool; and certainly no **one** grazing system is the best for all situations.

Good grazing management, then, is an art that requires fundamental information about the sagebrush-grass ecosystem, including characteristics and requirements of range plants and sound methods for recognizing and evaluating changes resulting from grazing use. It especially requires sensitive indicators of trend to allow early application of corrective measures, for some range abuse is apt to occur even under the best management unless discerning inspection and knowledgeable adjustments are integral parts of the system. If serious deterioration has already occurred, good management requires inexpensive and effective methods for controlling unwanted species and for establishing desirable vegetation.

## INTEGRATION OF MULTIPLE USES AND VALUES

Although the primary use of sagebrush-grass range has been grazing by domestic livestock, more and more recognition has been given during recent years to its use as wildlife habitat, as watershed for the production of quality water, as wildland with innumerable recreation opportunities, and as a resource reserve available for supplying presently unforeseeable needs. Consequently, the once basic premise of maximum livestock production must always be tempered with a stewardship philosophy of conservation of the entire resource and protection from irrevocable damage. Vegetation manipulation through livestock grazing, selective plant control, and introduction of new species through seeding and planting can greatly influence habitat quality and wildlife populations. Each species has peculiar food and cover requirements, which must be carefully considered along with interrelations of domestic livestock.

Though not sagebrush-grass range per se, inclusions of aquatic and riparian habitat, meadows, patches of trees, and so forth, are extremely important to fish and wildlife. Streambank vegetation influences water temperature, which is critical for many species of fish. Streamside vegetation also affects food production in streams and chemical control of the water. Furthermore, it serves as a buffer to prevent excessive intrusion of sediments or other foreign substances from the adjacent rangelands. Excessive runoff from poor condition sagebrush-grass ranges—as well as direct damage to riparian vegetation and streambanks from livestock grazing and trampling, road construction, and recreational use—has caused serious problems in many areas of the Great Basin. Satisfactory restoration may often require innovative and expensive measures. Meadows and patches of trees can also have benefits to wildlife far out of proportion to the small area they occupy. Since all of these inclusions are normal components of most sagebrush-grass ranges and since damage from concentrated use is often severe, they must be given special consideration in the development of any range management prescriptions.

## Terrestrial Wildlife and Habitat Relations

The faunal composition of any sagebrush ecosystem depends upon the kind and amount of sagebrush and associated species (McAdoo and Klebenow 1979); consequently, a habitat type classification would be a useful tool in evaluating potential for supporting wildlife. Inclusions of other vegetation types or aquatic areas are important and may be the reason for the presence of certain animals. Also, fauna may vary with the intensity of grazing by domestic livestock. A few animals such as pygmy rabbits (*Brachylagus idahoensis*), sagebrush voles (*Lagurus curtatus*), Great Basin pocket mice (*Perognathus parvus*), least chipmunks (*Eutamias minimus*), sage grouse (*Centrocercus urophasianus*), and Brewer's sparrows (*Spizella breweri*) are highly dependent upon sagebrush-grass communities. But more adaptable species occur in other habitats as well (McAdoo and Klebenow 1979), including mule deer (*Odocoileus hemionus*), pronghorn antelope (*Antilocapra americana*), bighorn sheep (*Ovis canadensis*), coyotes (*Canis latrans*), kit foxes (*Vulpes macrotes*), bobcats (*Lynx rufus*), black-tailed jackrabbits (*Lepus californicus*), and a wide variety of other rabbits, rodents, songbirds, and birds of prey.

### SAGE GROUSE

Big, threetip, silver, low, and black sagebrush habitat types are important for supplying breeding, nesting, and feeding requirements of sage grouse ( Rasmussen and Griner 1938; Klebenow 1969; Klebenow 1972). Because of this dependence of sage grouse on sagebrush-grass ranges, wildlife biologists have been concerned about effects of livestock grazing, plant control, and revegetation practices. Klebenow and Gray (1968) emphasized the importance of forbs in the diet of both chicks and adult birds, and cautioned that spraying for sagebrush control also destroys the forbs and creates an unsuitable environment for sage grouse, especially the juveniles.

Klebenow (1969) reported that sage grouse did not nest in, nor did broods occupy, areas of tall, dense sagebrush with little understory. He concluded that controlling such sagebrush and allowing native forbs and grasses to recover their former productivity would greatly improve the habitat for sage grouse. Apparently, fire is an ideal tool for achieving the management objective of a diverse habitat providing all the needs of sage grouse (Klebenow 1972). Since included areas of meadows and other grassy openings are also desirable for sage grouse, grass seedings for livestock range improvement can often be used to good advantage for both. Sage grouse subsist on moisture from green vegetation and from rain or dew in spring and early summer. Free water, however, is needed to satisfy requirements later in the season when forage becomes dry. Water developments should allow longer occupation of otherwise suitable sagebrush-grass range at the lower altitudes and more flexibility in its use. At any rate, good range condition for livestock appears to coincide with good habitat for sage grouse, providing sufficient sagebrush is maintained to supply their dietary needs. Sage grouse are solely dependent upon sagebrush for food from October through April of each year (Autenrieth 1980).

### MULE DEER

Although somewhat scarce during early pioneer days, mule deer populations increased greatly during the second quarter of the 20th century (Julander and Low 1976). Shrubs, forbs, and grasses associated with sagebrush ecosystems are important in mule deer diets. Sagebrush-grass vegetation is especially important as winter range because of large acreage and general lack of deep snow. Sagebrush is an important part of a deer's diet in winter, whereas grasses are used primarily in the spring and forbs in the summer. Relative value of various habitat types has received only limited study. However, Tueller and Monroe (no date) observed that big and black sagebrush communities in Nevada, especially those supporting an abundance of bitterbrush, were preferred by deer.

Big sagebrush is a superior winter forage for mule deer. It is high in crude protein and coefficient of digestion (Welch and McArthur 1979a,b). Big sagebrush and curlleaf mountain mahogany are the only two winter forages of the nine reviewed by Welch and McArthur (1979a) that exceed the minimum protein requirement for wintering mule deer. The essential oils of sagebrush have been thought to inhibit digestion by mule deer rumen microflora (Nagy and others 1964). Recent work by Welch and Pederson (1981), however, indicates that the concentrations of essential oils in the rumen are too low to be inhibitory. The two scientists conclude that big sagebrush is a highly digestible winter browse. Although some other browse species are preferred to big sagebrush by wintering mule deer (Smith and Hubbard 1954), it is nevertheless highly utilized (Kufeld and others 1973) and nutritious (Welch and McArthur 1979a). Some sagebrush stands are preferred over others as browse (Hanks and others 1973; Welch and McArthur 1979a).

Because sagebrush-grass range deterioration from livestock grazing usually resulted in too much sagebrush and too little herbaceous vegetation, range restoration often involved sagebrush destruction and seeding of perennial grass. However, more recent efforts in big-game range restoration by Plummer and others (1968) have used mixtures of grasses, forbs, and shrubs for revegetation, and the result has been favorable for wildlife habitat and livestock range, as well as for other uses and values.

### PRONGHORN ANTELOPE

Shrubs are the primary diet of antelope during most of the year, although forbs are important during spring and summer. Despite the prominence of sagebrush in their diets, antelope appear to do best where shrub cover is moderate and low in stature (Urness 1979). Although big sagebrush is apparently the most important species for antelope, black, low, and silver sagebrushes may be preferred in various situations and localities (Smith and others 1965). According to Beale and Scotter (1968), the general diet of antelope in Utah under good forage conditions consists mostly of succulent grass and forbs during the early spring, mostly succulent forbs during the late spring and summer, forbs and shrubs in the fall, and shrubs during the winter. As with livestock range, dense stands of big sagebrush with sparse herbaceous understories can be improved by spraying or burning followed by seeding, if necessary, to restore the forbs and grasses. Such forbs as dryland alfalfas, globemallow (*Sphaeralcea* spp.), small burnet, and Lewis flax should be especially good for antelope ranges.

The use of water by antelope is related to forage moisture (Beale and Scotter 1968). When the forage is succulent, antelope do not require any drinking water, but they drink water regularly during drought if it is available. Although antelope can survive long dry periods without drinking water, their physical condition may be impaired and subsequent winter survival may be low. During drought, does and fawns tend to restrict their grazing to areas close to available water. According to Yoakum (1979), antelope will use every kind of available water source: springs, creeks, rivers, lakes, reservoirs, and troughs fed by windmills or springs. Installation of catchments (guzzlers) on poorly watered ranges have also been successful. Such water developments are relatively maintenance-free and serve a variety of wildlife and domestic livestock. Manipulation of water availability as a means of livestock control should be discontinued (Urness 1979).

Fences to control livestock distribution can create serious problems for antelope survival. Although high death rates result from entanglement, more important are the effects of entrapment and restriction of necessary migration on survival (Yoakum 1979). Fencing, which creates better livestock distribution and alleviates concentration in stream bottoms and around ponds and seeps, also causes a dilemma for the range manager. Such activities can be of great importance to condition of wildlife and fish habitats within sagebrush-grass range areas (Urness 1979). When fence construction is deemed necessary, use of net wire should be avoided and the following specifications (Yoakum 1979) should be followed for barbed wire:

1. Bottom wire 16 inches (40 cm) from the ground, next wire up 10 inches (25 cm), third wire up another 10 inches (25 cm).
2. Bottom wire should be smooth as antelope usually go under.
3. No stays between posts.
4. Important migration routes should allow for low height or lay-down panels.
5. Fenced areas should be as large as possible so that the antelope will have maximum opportunity to obtain all basic habitat requirements.

#### SONGBIRDS

Alterations in songbird populations are largely related to effects of grazing and plant control on vegetation structure and composition. In Wyoming, Brewer's sparrows' use of a sprayed sagebrush stand 1 and 2 years after treatment was 67 and 99 percent lower, respectively, than use in an unsprayed stand, and no evidence of nesting was found in the sprayed stand (Schroeder and Sturges 1975). Because this species builds its nest in the shrubs, burning or mechanical removal of sagebrush would presumably have an effect similar to spraying. Populations of Brewer's and vesper sparrows (*Pooecetes gramineus*), however, were not reduced by treatments that produced only a partial kill of sagebrush (McAdoo and Klebenow 1979). Apparently, most species of songbirds in the sagebrush-grass ecosystem are dependent upon shrubs.

#### RABBITS AND RODENTS

A wide variety of small mammals are associated with sagebrush-grass vegetation. Pygmy rabbits depend upon sagebrush for both food and cover (Green and Flinders 1980). In southeastern Idaho, sagebrush was eaten throughout the year, although in lesser amounts in summer (51 percent of the diet) than in winter (99 percent). Grasses and forbs were eaten throughout the summer (39 and 10 percent, respectively), but greatly decreased in the diet through fall and into winter. Thick clumps of tall sagebrush are critical to their habitat. Least chipmunks are also highly dependent upon sagebrush communities (McAdoo and Klebenow 1979) and may be the most abundant rodent.

Effects of rodents on sagebrush-grass vegetation and other factors of the ecosystem are variable and not well defined. Interactions with each other, predators, and livestock are complex but may not be important in application of ordinary range management practices. However, if endangered species are involved, a more critical evaluation of interrelations will be necessary.

### Riparian and Aquatic Habitat Relations

Because of the importance of riparian and aquatic inclusions as livestock range, as wildlife and fish habitat, and as recreational areas, they must be given special consideration in management plans. Livestock, especially cattle, tend to concentrate in meadows and drainages and utilize the vegetation much more closely than that on the range as a whole. Such use can have serious effects on the riparian environment by changing or reducing natural vegetation, or by actually eliminating riparian areas as a result of channel widening or degradation and lowering of the water table (Platts 1979). The most apparent effects on fish habitat are reduction of shade and cover along with increases in stream temperature, changes in stream morphology, and addition of sediment from bank sloughing and offsite soil erosion. Destruction of riparian vegetation also has serious impacts on habitat values for several terrestrial wildlife species and on recreational values associated with water, shade, desirable ground cover, and esthetics.

Extraordinary management practices will generally be necessary to protect and improve riparian and aquatic areas. Although riding and herding, rotation of use, and providing substantial periods of rest may be sufficient for some situations, others may require revegetation, reduction in livestock numbers, total exclusion of livestock by fencing, and perhaps addition of erosion control structures. In any event, these riparian and aquatic inclusions must be considered as key areas in evaluating success of management on many sagebrush-grass ranges.

### Soil Stabilization and Watershed Protection

Maintenance or improvement of soil stability and protective watershed cover is not only an objective of sagebrush-grass range management but also a criterion that can be used to judge the effectiveness of management practices. Both livestock grazing and direct range improvement practices such as sagebrush control and seeding must be properly administered or damage may exceed benefits. Copeland (1963) pointed out that the unstable soils and steep topography in certain areas of the West, combined with such disturbing climatological phenomena as droughts and floods, can cause substantial yields of sediment even on ungrazed watersheds. With the added impact (even though temporary) of grazing or vegetation manipulation, serious runoff and erosion can occur. Fortunately, however, such range management practices are usually compatible with the basic goals of soil and vegetation stability in most sagebrush-grass ecosystems.

### Esthetic and Recreational Values

Although beauty of the outdoors is often associated with the spectacular or unusual, it can also exist in the ordinary or commonplace. Well-managed rangelands are beautiful to those who view them impartially, as well as to those who understand the concepts of land use and the long-range objectives of various management practices (USDA Forest Service 1965). Even the somewhat drab sagebrush-grass range can be interesting and perhaps beautiful when it is seen as an important watershed, a producer of livestock, or a valuable wildlife habitat.

Ranges with vigorous stands of vegetation present a constantly changing panorama. They may be a patchwork of contrasting plant communities, often with well-defined borders, or they may be single communities such as sagebrush-grass that change in appearance from season to season or even from day to night. To many people, the view is improved when it includes good livestock, vigorous vegetation, and stable soils. Enjoyment of the pastoral scene is increased by the recognition of a good job of land and livestock husbandry. Just as livestock and vegetation are vital parts of the range scene, fences, corrals, and water developments add interest and beauty if they are made to blend in with the landscape. Appearance, as well as utility, is an important factor in the design of range structures. Fences, windmills, troughs, and even corrals can be designed to harmonize with the landscape.

Wild animals of the sagebrush-grass ecosystem are also a source of interest and beauty. To some people the ultimate in outdoor enjoyment is viewing a deer or antelope in its native habitat, or a coyote slinking across an opening in the sagebrush. To others it is the sight of a gracefully soaring hawk or the song of an unseen bird. Enjoyment of wildlife, however, is heightened if it is recognized as an intrinsic part of a landscape where all living creatures are part of the biotic community.

On the other hand, a sagebrush-grass range with deteriorating vegetation and eroding soil presents an ugly picture from both esthetic and resource-management standpoints. Restoration of desirable grasses, forbs, and shrubs not only adds beauty, but also improves the livestock forage and wildlife habitat.

## SUMMARY

1. Sagebrush-grass range is an important resource for production of livestock and wildlife, watershed values, and a wide variety of recreational activities.

2. Unfortunately, much of this valuable resource was depleted during early years of western settlement. Despite several decades of "improved" management, production of the sagebrush ecosystem is far below its potential. Restoration of desirable vegetation is needed.

3. The North American sagebrushes comprise subgenus *Tridentatae* (Rydb.) E. D. McArthur of the genus *Artemisia* L. Twenty taxa have been identified and described.

4. Edaphic characteristics are important in the distribution of sagebrush taxa. Although there are many exceptions, general distribution is related to soil moisture, temperature, depth, and parent material.

5. Several classification systems have been developed for sagebrush ecosystems. The habitat type concept has gained considerable acceptance by the Forest Service, whereas the range site classification system is preferred by the Soil Conservation Service and Bureau of Land Management. Both systems are based on climax vegetation, but different factors are emphasized.

6. Some 14 habitat types of dwarf sagebrush and 29 habitat types of big sagebrush have been described, but this is far from a complete treatment. Probably twice that many are in existence.

7. Because of the number involved, individual management prescriptions cannot be developed for or applied to each habitat type. Rather, general management guides are presented with necessary modifications for certain habitat types.

8. Range condition or health is the status of vegetal cover or soil in relation to a standard or ideal for a particular habitat type or site. Trend is change in condition. Reliable judgment of condition and trend is essential to effective evaluation of the success or failure of management practices.

9. Information on condition and trend of sagebrush-grass ecosystems is meager. However, general guides were developed for southern Idaho, and these can be used for a variety of habitat types and sites.

10. Condition and trend of sagebrush-grass ranges cannot be adequately evaluated without an examination of included riparian and aquatic areas, which may be particularly sensitive indicators of what is happening on the range as a whole.

11. Management objectives may be described in several ways: wise multiple use, maintenance or improvement of vegetation, or optimum sustained-yield of livestock and wildlife consistent with other uses and values. Although emphasis may vary with specific conditions or situations, it seems logical to direct primary attention to conservation of the basic resource—soil and vegetation.

12. Although stable soil is always a prerequisite to satisfactory condition, effectiveness of management is usually judged by vegetal response. Generally, a reduction in sagebrush and an increase in perennial grasses and forbs is needed.

13. Burning, spraying, and mechanical methods have all been used effectively to control sagebrush.

14. Fire is a natural phenomenon that can successfully be used to reduce sagebrush and allow increases in grasses and forbs. Big sagebrush habitat types can usually be burned, but habitat types of dwarf species may not provide enough fuel to carry a fire.

15. Response of mountain big sagebrush and associated species was studied on a prescribed burn in southeastern Idaho for 30 years. With few exceptions, production of grasses and forbs decreased the year after burning, but recovery was rapid, especially by rhizomatous species. Sagebrush was practically eliminated and its reestablishment from seed was very slow, whereas rabbitbrush and horsebrush sprouted profusely and quickly regained their original size. However, after increasing during the first 12 years following burning, nearly all species of grasses, forbs, and shrubs decreased during the next 18 years as sagebrush regained dominance.

16. Response of individual plants to fire is highly variable. However, if initial effects that are generally injurious to all species are ignored, then the following classification is fairly reliable: (a) **severely damaged**—shrubs that are unable to sprout, suffrutescent forbs, and fine bunchgrasses with densely clustered culms such as Idaho fescue; (b) **only slightly affected**—coarse bunchgrasses, fine bunchgrasses with loosely clustered culms such as bluegrass, forbs that are neither suffrutescent nor rhizomatous, and shrubs with a limited sprouting habitat; and (c) **considerably benefited**—shrubs with a strong sprouting habit, rhizomatous grasses, and rhizomatous forbs.

17. Since vegetal response is closely related to burn intensity, winter or early spring burns will be less injurious to most species than those in summer or fall when soil moisture is low and temperatures are high.

18. Nutrients contained in vegetation are released by fire in the form of volatiles (nitrogen and sulfur) or ash (phosphorus,

potassium, calcium, magnesium). The former are at least partially lost to the system, but the latter generally are added to the soil.

19. For the most part, burning can be reliably prescribed only for habitat types of threetip sagebrush and basin, Wyoming, and mountain big sagebrushes.

20. Burning as a range improvement measure should be implemented only after alternatives have been considered and a satisfactory plan has been developed and approved. Where, when, and how to burn should all be addressed, as well as followup management.

21. Since effective control of big, low, black, silver, threetip, and alkali sagebrushes with 2,4-D has been reported, it is assumed that all sagebrushes are susceptible to this chemical, especially in the spring when the plants are actively growing.

22. Because of the effects of 2,4-D on species associated with sagebrush, composition of the vegetation must be carefully considered. Since perennial grasses are seldom damaged, they can be expected to increase as a result of reduced competition from sagebrush. However, many perennial forbs and shrubs are severely damaged by spraying, and this probable damage to desirable species must be evaluated in relation to anticipated benefits.

23. Several mechanical methods for sagebrush control have been used successfully since the 1930's, including plowing or disking, root cutting, beating or shredding, railing, and chaining. Choice of method depends upon such factors as size and density of sagebrush, need to destroy or preserve understory vegetation, size of area to be treated, rockiness and other characteristics of the site, and availability of equipment.

24. Insects, small mammals, and large herbivores are all possibilities for regulated biological control of sagebrush. However, only grazing of sheep during the late fall or winter has shown significant promise to date.

25. Control measures apparently do not have serious long-term impacts on either vegetation or soil. If necessary, sagebrush control at 20-year intervals should be tolerable for most situations.

26. On sagebrush-grass ranges that have been depleted by past abuses, neither complete protection nor conservative grazing can restore a desirable vegetal cover within a reasonable time. Consequently, removal of competing vegetation, especially sagebrush, and seeding with desirable grasses, forbs, and shrubs is the only satisfactory method of restoration.

27. Since early efforts in sagebrush-grass range revegetation were aimed at increasing livestock forage, establishment of a good stand of perennial grass was the usual objective. With the recognition of the limited value of single species, more and more attention was given to mixtures that would improve multiple-use values.

28. In recent years, increasing emphasis has been placed on the use of shrubs in revegetation mixtures. Studies have demonstrated that a number of native and exotic shrubs can be successfully established within most sagebrush-grass communities.

29. Guides developed by Plummer and others (1968) for big-game ranges are generally appropriate for revegetation of sagebrush-grass ranges: changes in plant cover must be deemed necessary; terrain and soil must be suitable for selected restoration; precipitation must be adequate; competition from existing vegetation must be minimal; only adapted species and strains should be planted; mixtures should be generally used; sufficient good quality seed should be planted; seed must be covered; planting should be done in the season that promises the best environment; and revegetated areas must be properly managed.

30. Although the influence of grazing may be exerted in many ways, the most obvious is reduction in volume of herbage and area of photosynthetic surface. Defoliation of herbaceous species is most injurious at the time growth is well advanced in the spring, root reserves have been expended, and substantial regrowth during the dry summer is impossible.

31. Since most grasses and forbs are more palatable to livestock than are shrubs, especially during the growing season, the tendency is for sagebrush and other shrubs to flourish at the expense of herbaceous species. However, properly regulated grazing can be compatible with a desirable mixture of vegetation.

32. Five common grazing systems have been described, and all have been used on sagebrush-grass ranges: continuous, rotation or alternate, deferred, rotation-deferred, and rest-rotation.

33. A common goal of all systems should be reduction of damage from grazing while promoting beneficial effects, and many systems appear equally effective. Various combinations of rotation and deferment, as well as continuous grazing, have all proven to be successful where such factors as range condition, kind of livestock, stocking rate, season, and intensity were given proper consideration.

34. Although rest-rotation has been widely accepted as a panacea for range management problems, data are not available to demonstrate its real worth or to sort out the contribution of such important factors as plant control, revegetation, water development, fencing, and removal of trespass livestock—all of which have accompanied the application of rest-rotation grazing on Federal ranges. Certainly, no conclusive proof exists that rest-rotation is more effective than other systems on sagebrush-grass ranges.

35. Rate of stocking—balancing numbers of grazing animals with forage resources—is the most important part of good grazing management. Although grazing capacity can be estimated, actual grazing with continuing evaluation of range and livestock performance is necessary, and precise determination of grazing capacity by other means should not be attempted.

36. Range condition is especially important in the development of satisfactory management prescriptions. Depleted and poor condition ranges will respond slowly to even the best grazing management because pressure is kept on the already sparse stand of desirable grasses and forbs by grazing animals and by competition from sagebrush and other unpalatable species.

37. Kind of livestock is another important influence, and rotation of use between cattle and sheep can be beneficial, especially to fair and good condition sagebrush-grass ranges.

38. Good grazing management is an art that requires fundamental information about the sagebrush-grass ecosystem, including characteristics and requirements of range plants and sound methods for recognizing and evaluating changes. It especially requires sensitive indicators of trend to allow early application of corrective measures, for some range abuse is apt to occur even under the best management unless discerning inspection and knowledgeable adjustments are integral parts of the system.

39. Although past use of sagebrush-grass range has centered around livestock production, more and more recognition has been given in recent years to other uses and values. Vegetation manipulation through livestock grazing, plant control, and revegetation can greatly influence habitat quality and wildlife populations.

40. Inclusions of aquatic and riparian habitat, meadows, patches of trees, and so forth, have benefits to wildlife far out of proportion to the small area they occupy. They deserve extraordinary management and must be considered as key areas in evaluating effectiveness.

41. Deteriorating vegetation and eroding soil present an ugly picture from both esthetic and resource management standpoints, but even the somewhat drab sagebrush-grass range can be interesting and beautiful when seen as an important watershed, a producer of livestock, or a valuable wildlife habitat.

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## APPENDIX

### KEY TO THE TAXA OF ARTEMISIA (From Beetle 1960)

Head composed of both 2-lipped ray flowers and regular disk flowers; vegetative branches with leaves shallowly and sharply 3-toothed

1. *A. bigelovii*

Head composed only of 5-toothed disk flowers; leaves of vegetative branches entire or lobed; if lobed, usually not both sharply and shallowly

Dwarf desert cushion half-shrubs about 1 dm. tall; leaves pinnatifid into 3-11 linear-subulate divisions, green; outer involucral bracts linear to lanceolate, nearly glabrous

2. *A. pygmaea*

Taller shrubs; leaves entire or toothed at the apex, or, if dissected into linear divisions, then canescent; outer involucral bracts orbicular or ovate, sometimes narrowed to an herbaceous tip, usually densely pubescent

Plants erect, crown spreading above the base, the older branches rigid, at least the first fascicle leaves cuneate, at least the first leaves lobed; or sometimes deeply so; dying after burning; subtending leafy bracts of the inflorescence shorter than the heads

Dwarf plants (1-3 dm. tall) with small leaves mostly less than 1 cm. long; leaves flabelliform; inflorescence dark brown and very persistent the year following seed shedding; involucre very narrowly campanulate

3. *A. nova*

Erect plants (except that dwarf forms are common in A. *tridentata* and *A. arbuscula*), usually more than 3 dm. tall, commonly much higher; most leaves more than one cm. long, old inflorescence stalks gray and weakly persistent; involucre campanulate to broadly campanulate

Involucres narrowly campanulate, heads few-flowered, often in open panicles; leaves narrowly cuneate, not layering

Leaves short, branches flexuous; narrowly racemose paniculate

Most leaves coarse, cuneate

4. *A. arbuscula* subsp. *arbuscula*

All leaves fine, deeply trifid

5. *A. arbuscula* subsp. *thermopola*

Leaves elongate, branches stiff; openly paniculate

Inflorescence branches erect; achene glabrous

6. *A. tridentata* subsp. *tridentata*

Inflorescence branches recurved; achene often hairy

7. *A. tridentata* subsp. *tridentata* forma *parishii*

Involucres broadly campanulate; heads many-flowered; leaves broadly cuneate; often layering

Late maturing (seed ripe in October); leaves usually truncate, merely toothed, or occasionally acutely lobed

Heads 3-4 mm. broad; leaves not unusually large, often very much reduced

8. *A. tridentata* subsp. *vaseyana*

Heads 4-5 mm. broad; leaves unusually large, at times 6.5 cm. long, and 2 cm. broad

9. *A. tridentata* subsp. *vaseyana* f. *spiciformis*

Early maturing (seed ripe by the end of August), at least the first leaves (which subtend the fascicle leaves) deeply lobed; lobes of all the leaves obtuse or rounded

10. *A. longiloba*

Plants dwarf or prostrate spreading, the older branches flexuous, most leaves entire, pointed, cleft or deeply lobed (*A. cana* is often erect but has simple, or irregularly lobed, pointed leaves; *A. tripartita* subsp. *tripartita* is often erect but has deeply divided to very narrowly linear leaves; *A. rigida* likewise may be erect but never has truncate cuneate leaves); although evidence is lacking in some cases apparently either stump-sprouting, layering, or spreading from underground rootstocks after burning; subtending leafy bracts of the inflorescence longer than the heads

Heads commonly 4-6 mm. broad; leaves simple, cuneate, lanceolate, or sometimes deeply lobed

Leaves persistent, deeply notched with rounded lobes; inflorescence an elongate spike of few often darkly purplish heads; young stems green

11. *A. rothrockii*

Leaves deciduous in cold winters; simple and entire, or with acute lobes; inflorescence paniculate, heads green; young stems white

Leaves broadly lanceolate, simple, mostly over 2 cm. long

12. *A. cana* subsp. *cana*

Leaves narrowly lanceolate, simple to deeply divided with asymetrical, acute lobes, canescent to green; mostly under 2 cm. long

Leaves weakly canescent to green; plants along mountain streams

13. *A. cana* subsp. *viscidula*

Leaves silvery canescent, the pubescence loose; plants of poorly drained or alkaline soils

14. *A.* cana subsp. *bolanderi*

Heads commonly 2-4 mm. broad; leaves divided into 3-5 linear, obtuse lobes

Inflorescence an elongate spike, the subtending bracts of equal length to the tip

15. *A. rigida*

Inflorescence an open or racemose panicle, the subtending bracts smaller toward the tip

Leaves up to 3 cm. long, at most the lobes 1 mm. broad

Plants tall (up to 2 meters); leaves seldom over 2 cm. long, the lobes 0.50 to 0.75 mm. wide

16. *A. tripartita* subsp. *tripartita*

Plants dwarf (rarely over 1.5 dm. tall); leaves often 3 cm. long, the lobes 1 mm. wide

17. *A. tripartita* subsp. *rupicola*

Leaves up to 4 cm. long, each lobe 2-3 mm. broad

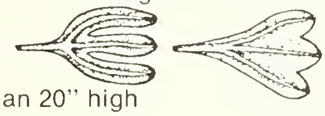
18. *A. argillosa*

# KEY TO *ARTEMISIA* (SECTION TRIDENTATAE) IN OREGON
(from Winward 1980)

1a Leaves entire[1] 

2a Leaves silver-gray, plants from internally drained basins with seasonal flooding ---------- *A. cana ssp. bolanderi*

2b Leaves green-gray, plants along stream bottoms or meadow margins from mid to high elevations ---------- *A. cana ssp. viscidula*

1b Leaves divided or lobed 

3a Mature[2] shrubs less than 20" high

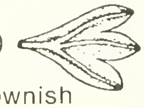
4a Leaves divided (lobe length > 3 times width) 

5a Flower stalk leaves divided, inflorescence spicate, all leaves winter deciduous ----------  ---------- *A. rigida*

5b Flower stalk leaves entire 

6a Inflorescence paniculate, upper flower stalk leaves much longer than flower heads ---------- *A. tripartita ssp. tripartita*

6b Inflorescence spicate or racemose, flower stalk leaves equal or only slightly longer than flower head ---------- *A. arbuscula ssp. thermopola*

4b Leaves lobed (lobed length < 3 times width) 

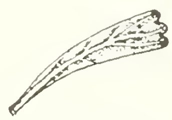
7a Inflorescence paniculate, seed stalks brownish and persist into following year ----------  ---------- *A. nova*

7b Inflorescence spicate or racemose, seed stalks grayish and weakly persistent 

8a Seeds mature mid-July to mid-August ---------- *A. longiloba*

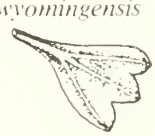
8b Seeds mature late August to October ---------- *A. arbuscula ssp. arbuscula*

3b Mature shrubs taller than 20"

9a Uneven topped shrubs, flower stalks arise throughout crown  

10a Mature plants > 40" in height, leaf margins straight ---------- *A. tridentata ssp. tridentata*

10b Mature plants < 40" in height, leaf margins belled outward ---------- *A. tridentata ssp. wyomingensis*

9b Even topped shrubs, flower stalks arise from upper crown and extend above foliage  

11a Leaf margins belled outward, inflorescence spicate or racemose ---------- *A. arbuscula ssp. arbuscula* 

11b Leaf margins straight, inflorescence paniculate 

12a Four to six flowers per head ---------- *A. tridentata ssp. vaseyana* 

12b More than six flowers per head, plant often layering ---------- *A. tridentata form spiciformis* 

1 Key based on persistent (overwintering) leaves unless otherwise noted.

2 Mature infers at least 20 years old (see xylem layers).

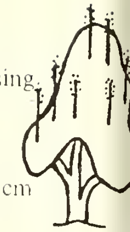
# TAXONOMIC KEY AND DESCRIPTIONS
(from Winward and Tisdale 1977)

Three important features of the big sagebrush group must be recognized for identification purposes:

1. Leaves from the flowering branches are not always reliable for taxonomic separation.
2. Leaves of the vegetative shoots are of two types, ephemeral or persistent. Ephemeral leaves are larger and often irregularly lobed. They are among the earliest to develop, and are shed as the season advances. Persistent leaves are typically 3-lobed, and over-winter on all big sagebrush taxa. Differences between ephemeral and persistent leaves, and leaf variation among taxa of big sagebrush are shown in Fig. *a*.
3. Leaf and growth form characteristics are most easily distinguished after plants have flowered.

The following key is designed for separations based on persistent leaves only. Additional characteristics are provided under the individual plant descriptions. Illustrations of some characters used in the key are presented in Fig. *b*.

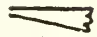
**Artemisia Tridentata Key**



1 Uneven topped shrubs, flower stalks arising throughout the crown

2 Mature plants usually more than 100 cm (40 inches) in height, leaf margins straight

3 Leaves relatively long-narrow, L/W ratio 4.0 or greater, fluoresces reddish brown in alcohol (See Winward and Tisdale 1969.)



*A. tridentata* subspecies *tridentata*

3 Leaves relatively long-broad, L/W ratio less than 4.0, fluoresces bluish-cream in alcohol

*A. tridentata* "X"

2 Mature plants less than 100 cm (40 inches) in height, leaf margins curved outward, fluoresces reddish brown in alcohol

*A. tridentata* subspecies *wyomingensis*

1 Even-topped shrubs, flower stalks arising from upper crown and extending above foliage

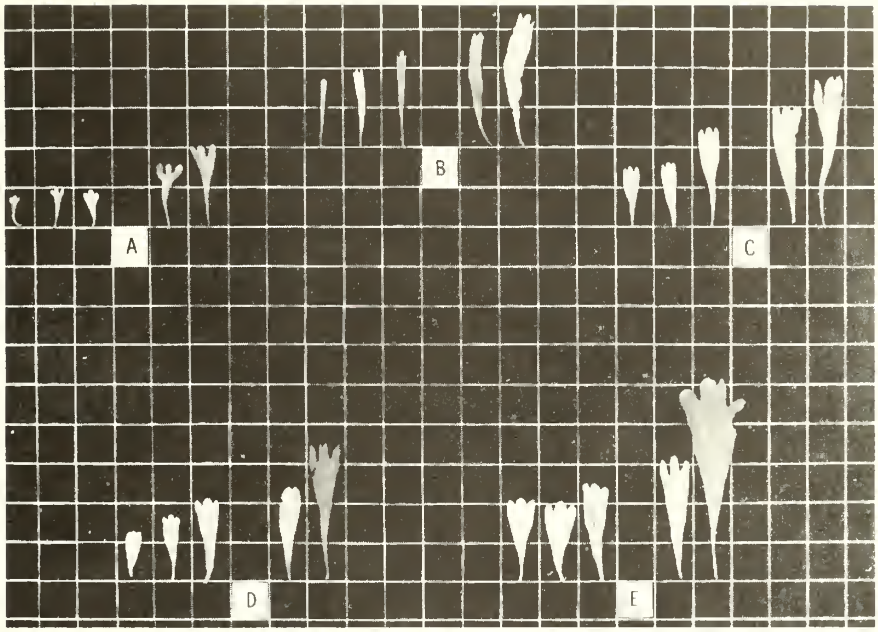
4 Flower heads less than 1.5 mm wide, 4-6 flowers per head, plants not layered, fluoresces bluish-cream in alcohol

*A. tridentata* subspecies *vaseyana*

4 Flower heads more than 1.5 mm wide, more than 6 flowers per head, plants often layered, fluoresces bluish-cream in alcohol

*A. tridentata* subspecies *vaseyana* form *spiciformis*

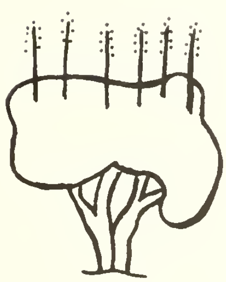
A subspecies *wyomingensis*
B subspecies *tridentata*
C subspecies *vaseyana*
D "X"
E form *spiciformis*




Note: The three leaves on the left of each group are persistent, and the two in the right of each group are ephemeral. The background is lined into 0.5 cm squares.

Fig. **a** Shapes and sizes of representative leaves of five big sagebrush taxa.

even topped shrubs (flower stalks from upper crown area only)



uneven topped shrubs (flower stalks throughout crown)

leaf margins curved outward (bell shape)

leaf margins straight (wedge shape)

leaves widest at lobe tips

leaves widest just below lobes

Fig. **b**. Diagramatic sketch of important morphological characteristics used in the taxonomic key of *Artemisia tridentata*

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Blaisdell, James P.; Murray, Robert B; McArthur, E. Durant. Managing Intermountain rangelands—sagebrush-grass ranges. Gen. Tech. Rep. INT-134. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 41 p.

This paper is a distillation of some of the most important information resulting from a half-century of research on sagebrush-grass rangelands. It has been prepared as a reference for managers and users of rangelands and as a help for planning and decisionmaking.

KEYWORDS: range management, range improvement, sagebrush-grass ranges, sagebrush ecology, sagebrush taxonomy

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General Technical
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November 1982

# Managing Campfire Impacts in the Backcountry

**David N. Cole and John Dalle-Molle**

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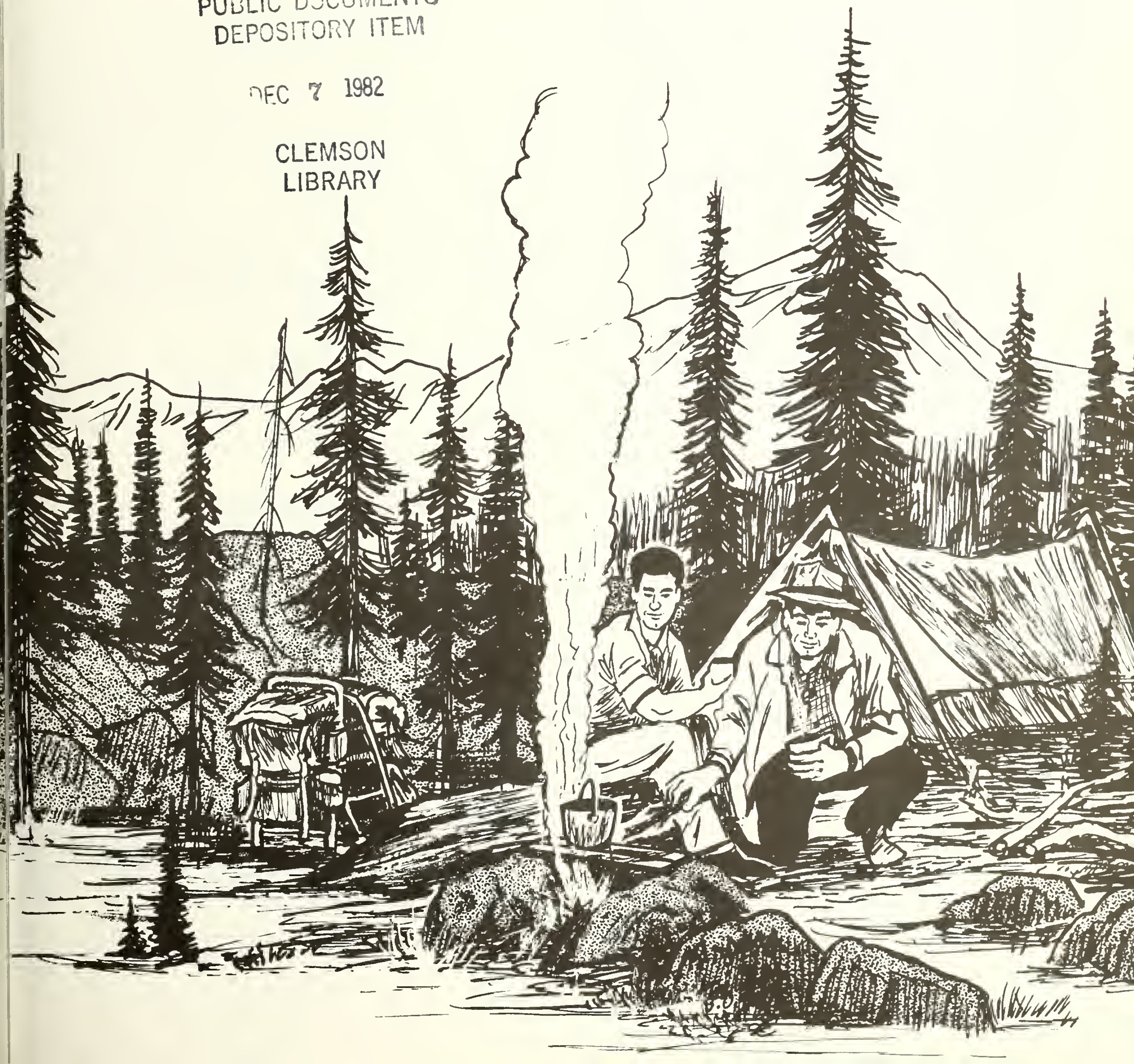

## THE AUTHORS

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**JOHN DALLE-MOLLE** has been resource management ranger at Denali National Park and Preserve, Alaska, since 1978. Before 1978 he was backcountry ranger at Mt. Rainier National Park, Wash.

## RESEARCH SUMMARY

The collecting and burning of wood in backcountry campfires have significant ecological and esthetic effects. The most important ecological effect is probably the elimination of large woody debris. Soil alteration in heavily used areas where campers are allowed or encouraged to build fires on previously undisturbed sites is also important. In most situations esthetic impacts are probably more severe than ecological impacts. The most common problems are proliferation of sites, elaborate fire ring construction, littering, and building fires on obtrusive sites such as in meadows.

The four basic strategies for managing campfire impacts are prohibition of fires, concentrating campfires on a few sites, dispersing fires to a large number of sites, and no action. The appropriateness of each strategy, which is dependent upon management objectives and characteristics of use and the environment, is discussed. Most areas are so diverse that strategies should vary between zones within each area. Each of these strategies will be effective only if a unique combination of management actions is taken.

The final two sections outline basic principles and procedures for promoting minimum impact campfire use and initiating a campsite rehabilitation program. These are two of the more complex and difficult actions that management may have to take.

## PREFACE

This report provides a summary of information and experience related to the management of campfires in backcountry areas. Although campfires are a widespread and prominent sign of human use, their impacts and significance are poorly understood. Management responses to these impacts include visitor education, regulations, site rehabilitation, and acceptance of impacts. These actions are often ineffective and in conflict because technical information is limited and management strategies are ineffective.

The information presented in this report should provide for the development of effective campfire policies and for practical techniques for achieving objectives. The report consists of four sections. Section one reviews the kinds of campfire impacts and their significance. The discussion is detailed because most of the conclusions have been extrapolated from indirectly related studies. Section two discusses the advantages and disadvantages of alternative strategies for managing campfire impacts and the management actions which must be taken if the strategies are to succeed. (This section should be most relevant to planning.) Section three describes minimum-impact campfire techniques and means of conveying this information to the visitor. Section four outlines methods for rehabilitating campfire sites, drawing heavily on techniques that have been successful in the Pacific Northwest. The last two sections are presented in a "how-to-do-it" manner intended for the manager who wants to start a campfire management program. More detailed sources of information are referred to in the text.

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## IMPACTS ASSOCIATED WITH CAMPFIRES

Fire sites, whether spots of blackened ground or elaborate fireplaces, are one of the most obvious signs of human use and impact in the backcountry. Managers of many backcountry areas have become concerned with both the esthetic impacts of fire sites and the ecological impacts of collecting and burning wood. Despite a paucity of research on this subject, it is possible to evaluate these impacts from indirectly related sources.

### Esthetic Impacts

In lightly used places, fire rings are often the only noticeable evidence of previous use (fig. 1). Even where rings have been destroyed, scattered charcoal and blackened rocks provide evidence that a site has been used before (fig. 2). Although this may be objectionable to visitors who are expecting to find absolutely pristine environments, most visitors sampled in nine backcountry areas actually preferred to find simple rock fire rings on campsites (Lucas 1980). As long as there are not numerous fire rings or an unnecessary proliferation of fire sites in any area, most visitors find fire sites to be a positive attribute.

**Figure 1.—In infrequently used areas, old fire sites are often the only noticeable evidence of human use.**

In addition to the proliferation of sites, the most significant esthetic problems occur when fire rings become elaborately constructed or filled with litter (fig. 3). In Yosemite National Park, for example, Lee (1975) found elaborately constructed facilities and copious quantities of litter to be major detractions from the visitors' overall trip satisfaction. Damage to trees and elimination of downed wood as a result of wood gathering are undoubtedly objectionable to some visitors but do not significantly reduce the satisfaction of most visitors (Lee 1975).

### Effects of Trampling

Trampling as a result of wood gathering, along with trampling while getting water, are the major causes of impacts beyond campsite boundaries. In Great Smoky Mountains National Park, the area disturbed by firewood collection was typically more than nine times the size of the devegetated area around campsites (Bratton and others 1978). In the Sierra Nevada, Davilla (1979) found typical wood scavenging distances to be about 200 ft (60 m). Saunders (1979) has documented pronounced shifts in understory composition in areas disturbed primarily by firewood collection. Soil is usually compacted and surface organic matter is disturbed.

Effects on small fauna may be even more pronounced. Duffey (1975), for example, has shown that the invertebrate fauna is altered at even lower trampling levels than the flora. Although such subtle changes may not be apparent to the visitor, they do represent a change in natural conditions occurring on an area almost an order of magnitude larger than other campsite impacts.

### Effects of Removing Downed Wood

There has been concern that firewood collection removes nutrients from collection sites. This should not be a problem in most cases, however, because very little of an ecosystem's nutrient capital is contained in the small boles and branches which are most frequently collected for firewood. Most of the nutrient capital is in the soil, and the tree components which in the long term are most important to nutrient cycling are the leaves or needles and twigs (see, for example, Weetman and Webber 1972; Weaver and Forcella 1977).

Boles and branches are also a relatively insignificant source of soil organic matter. Over the long term, leaves or needles and twigs contribute more organic matter than boles or branches, so removal of the larger size classes of downed wood should only slightly reduce total soil organic matter. However, removal of large boles eliminates the only source of large woody residue, which, in contrast to leaves or needles, twigs, and bark, has a unique functional role which cannot be replaced by finer organic materials.

Decayed wood has a greater water holding capacity than either mineral soil or humus. It also accumulates nitrogen, phosphorus, and sometimes calcium and magnesium, and is a significant site for nitrogen-fixing microorganisms (Harvey and others 1979). Consequently, removal of large woody debris can indirectly affect nutrient cycles. In many forests, dead wood is a preferred substrate for the seedling establishment and subsequent growth of some species (Jurgensen and others 1977; Schreiner 1978). Ectomycorrhizal fungi are also concentrated in decayed wood, particularly on dry sites and during dry periods (Harvey and others 1979). These organisms develop a symbiotic association with the roots of most higher plants, improving the plant's ability to extract water, nitrogen, and phosphate from infertile soils. Therefore, elimination of woody debris, through collection of firewood, may reduce site productivity, particularly on droughty or infertile soils.

Macrofauna are also affected by removal of large woody debris. For example, a shelterwood cut, in which all residues larger than 3 inches (7.5 cm) in diameter were removed, had significantly fewer total arthropods and particularly fewer arachnids (spiders) than similar shelterwood cuts in which less downed wood was removed (Fellin 1980). Small mammal and bird populations can also be affected by wood removal, where food sources are altered and living places and protected sites are eliminated. Large mammal populations should be essentially unaffected.

Use of wood not lying on the ground causes additional esthetic and ecological impacts. Trees close to campsites usually show a "browse line" where campers have broken off lower branches. Saplings are often felled and mature trees are scarred in areas where most of the downed wood has been removed. Scars often make a tree more susceptible to fungal attack. In some cases, standing snags have also been cut down. This eliminates important habitat for cavity-nesting birds and impairs the esthetic qualities of the area.

**Figure 2.—Even where fire rings have been broken up, the imprint of human use often remains in scattered charcoal and blackened rocks.**

**Figure 3.—Built-up firepit and rock chairs are disturbing to many visitors.**

## Effects of Campfires

Impacts resulting from campfires have been studied experimentally by Fenn and others (1976), although their experimental burns were probably more severe than typical campfires—140 lb (63.5 kg) of wood were ignited and allowed to burn completely, over 50 hours in some cases. They found that a single campfire altered organic matter to a depth of 4 inches (10 cm) or more, with a 90 percent loss of organic matter in the upper inch (2.5 cm) of soil. Impacts were less pronounced in fine-textured and moist soils, and where softwood fuels were burned.

Low-intensity fires, with temperatures below 400° F (200° C), may have relatively little effect on soil properties, while fires in which temperatures exceed 750° F (400° C) cause pronounced physical and chemical changes (Sertsu and Sanchez 1978). At temperatures above 750° F (400° C), most organic matter is consumed; most nitrogen, sulfur, and much phosphorus is lost; and the moisture-holding capacity and infiltration rates of the soil are reduced (Tarrant 1956; Miller and others 1974). Soil pH and the amounts of most cations increase (Isaac and Hopkins 1937). Fenn and others (1976) recorded maximum surface temperatures of campfires ranging from 350° F (180° C) to more than 1,340° F (730° C).

Fires also reduce the populations of mycorrhizal fungi. These populations may return to normal densities within a year of the burn, but species composition probably shifts and mycorrhizal seedlings remain less abundant for several years after fire (Tarrant 1956; Harvey and others 1976). Conifer reproduction has also been found to be less abundant and vigorous as much as 10 to 15 years after severe burns (Isaac and Hopkins 1937; Vogl and Ryder 1969).

Ash and charcoal from fires may also cause changes. Although generally favorable to growth, nutrients concentrated in ash can alter soil microorganism populations and lead to compositional changes in the understory. Surface charcoal increases soil temperatures; this can either increase seedling germination (De Keijzer and Hermann 1966) (fig. 4) or lead to increased heat injury and mortality (Tryon 1948). Tryon (1948) generally found little effect of charcoal on germination success, seedling growth, microorganisms, or mortality from damping-off fungi.

The effects of campfires, although perhaps not evident to most visitors, are pronounced and long lasting. If confined to very small areas—as individual fires are—the overall effects are probably insignificant. However, in many places dispersal of campers and, therefore, their campfires is encouraged. For example, in a 325-acre (132-ha) area around two lakes in the Eagle Cap Wilderness, Oreg., we found 221 campsites, some of which had multiple fire sites (fig. 5). Moreover, on many sites rangers and some visitors remove fire rings. Through analysis of long-term photographs, we have found that fire rings are often rebuilt in new locations on the site, effectively "moving" the impacts around the site. In these situations campfires do affect the ecology of a large area.

Finally, careless campers can allow a campfire to become a wildfire. Techniques designed to minimize the danger of wildfire, such as clearing a large area down to mineral soil, are often highly destructive. In areas of high fire danger campfire management options are severely constrained by the opposing interests of resource protection and fire safety.

**Figure 4.—On this campsite, tree seedlings are germinating only in the charcoal on the old fire site.**

**Figure 5.—Hundreds of old campfires mar the natural beauty and affect the ecology of this popular camping spot in the Eagle Cap Wilderness, Oreg.**

## Conclusions

Despite the lack of research specifically devoted to the impacts of firewood collection and burning, it is possible to draw some conclusions about probable effects. The frequently mentioned direct loss of nutrients is probably relatively unimportant; most of the probable ecological consequences of firewood collection and burning would be unnoticeable to most visitors. Large animals and live trees, for example, should be minimally affected. Undergrowth, small animals, and particularly microorganisms are more likely to experience changes in abundance and species composition.

Although the function of soil microorganisms in the ecosystem is poorly understood, the reduction of these populations, through removal and combustion of large woody material, trampling while gathering wood, and soil sterilization from the heat of the campfire, may be quite significant. Loss of mycorrhizal fungi may be of particular importance. The lack of mycorrhizal populations on many disturbed sites has led some authors to suggest that successful revegetation projects will depend upon an ability to maintain or reintroduce essential mycorrhizal fungi (Reeves and others 1979).

Some of these impacts could be reduced considerably if downed logs too large to break by hand were not removed for firewood. If these residues were left, changes in the soil's nutrient content and organic matter composition would be less significant and faunal habitats would be less severely altered. On the surface these logs provide sites protected from trampling where seedlings can regenerate (Schreiner 1978). They also provide natural dams, decreasing erosion potential. Incorporated into the soil, this woody debris provides important sites for microbial activity (Harvey and others 1979). Use of only smaller fuels would produce less charcoal and reduce visual evidence of previous fires. Finally, it would eliminate hacked and sawed-off logs.

Clearly, more research will be necessary before we understand the significance of firewood collection and burning. In particular, we need to know more about how long it takes for soils to recover from campfires. Although recovery rates will vary tremendously from site to site, observations of fire site recovery suggest that revegetation of well-used sites, even when assisted, will usually require at least 10 to 15 years. Less frequently used sites may recover more rapidly, but we have observed "rehabilitated" fire sites, used only once, where even visual recovery takes more than 1 year.

The effects of firewood collection then are probably insignificant except where wood supplies become so depleted that even large downed logs are used for firewood. This can occur with even moderate levels of use in forests or woodlands with low productivity and can occur on localized areas of heavy use in more productive forests. From both an ecological and a social perspective, the effects of campfires are also relatively insignificant—on account of their small size—except where they are allowed to proliferate or "move around" on a site. This situation can occur in moderately to heavily used areas where visitors are allowed to build fires wherever they want or where fire ring removal causes new rings to be built.

**Figure 6.—Multiple fire sites on a single campsite are an esthetic problem. This campsite in the Selway-Bitterroot Wilderness has four fire sites, three in front and to the right of the boulder in the center and one in the meadow at the left.**

The most significant esthetic problems are the proliferation of fire sites (fig. 6), elaborate fire ring construction, litter, and chopped trees and downed logs. These impacts are primarily a function of inappropriate visitor behavior and can happen anywhere.

## CAMPFIRE MANAGEMENT STRATEGIES

Development of an effective management program for dealing with campfire impacts requires (1) establishing management objectives, (2) choosing between alternative management strategies, and (3) enacting a specific action plan based on the chosen strategy. Figure 7 displays necessary decisions in a logical order and summarizes the actions that must be taken for a selected strategy to work.

Within most backcountry areas the significance of both the ecological and the esthetic impacts of collecting and burning wood varies greatly between ecosystem types. Moreover, amount of use, a critical determinant of the impacts which occur, also varies widely, tending to be concentrated along trail corridors and at a few destinations. For example, ecological impacts are likely to be relatively pronounced in heavily used timberline forests and negligible in trailless areas of productive forest. Esthetic impacts are of most concern in nonforested areas or around attractions such as lakeshores. Consequently, most areas would profit from an internal zoning system in which several of the strategies discussed below are employed. Much of the discussion that follows is concerned with situations in which each strategy is and is not appropriate.

It is also important to coordinate campfire management with other aspects of campsite management. In addition to the combinations of management actions which must be taken for a given strategy to be effective, it is also important to make certain that these actions do not conflict with other elements of a campsite management program.

With this in mind, the first decision for any zone or backcountry area is whether or not to allow campfires. This may be a decision that all campfire impacts are unacceptable. In this case, all campfires would be prohibited even in lightly used areas. This may be an objective in a strict nature preserve, although, to be consistent, visitor use of all types should be curtailed. More common are areas where some impacts would be acceptable, but it is not possible to allow fires and keep their impacts to an acceptable level. This is the situation in heavily used areas where wood production is low, such as in timberline forests (fig. 8) or arid regions, or where the esthetic impacts of fires are particularly severe, such as in subalpine meadows close to lakes (fig. 9).

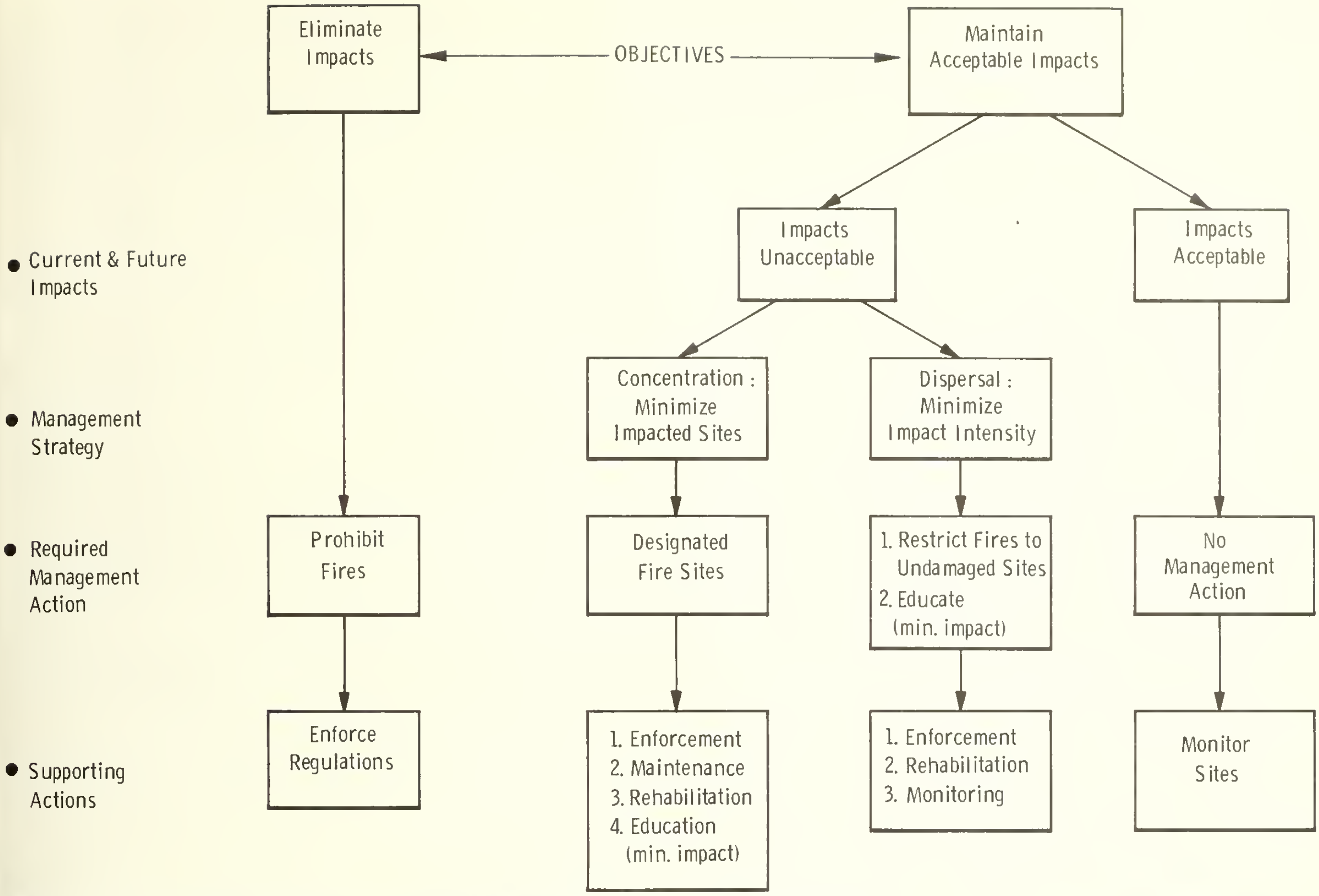


**Figure 7.**—Flow chart to aid in developing strategies and actions designed to manage backcountry campfires. Several strategies might be employed within different zones within one backcountry area.

**Figure 8.**—Wood fires should be prohibited in heavily used timberline sites where firewood is scarce.

**Figure 9.**—Old fire sites can spoil the beauty of meadows, particularly near popular lakes, even though loss of vegetation is often minimal.

Table 1.— Campfire policies for wildernesses and proposed wildernesses that permit overnight use (from 1978-79 census, USDA Forest and Range Experiment Station, Missoula, Mont.)

| Campfire policy | Agency: FS | NPS | FWS | BLM | Total |
|---|---|---|---|---|---|
| | Percent (Number) | | | | |
| Prohibit fires | 1 (1) | 40 (19) | 50 (17) | 0 (0) | 15 (37) |
| Permit fires | 99 (159) | 60 (28) | 50 (17) | 100 (11) | 85 (215) |
| Restrict fires to designated sites | 6 (9) | 39 (11) | 6 (1) | 0 (0) | 10 (21) |
| No restrictions | 84 (133) | 36 (10) | 94 (16) | 100 (11) | 79 (170) |
| Discourage wood fires | 28 (37) | 70 (7) | 6 (1) | 36 (4) | 29 (49) |
| Promote use of used sites | 18 (24) | 50 (5) | 0 (0) | 9 (1) | 18 (30) |
| Promote use of undamaged sites | 19 (25) | 0 (0) | 0 (0) | 0 (0) | 15 (25) |
| Total areas reporting | 160 | 47 | 34 | 11 | 252 |

Currently, 15 percent of all existing and proposed wilderness units that permit overnight use prohibit campfires (table 1). Most of these areas have little firewood, being located in arid regions or at high altitudes; many of them receive little use, however. In some cases fires are prohibited because of high fire danger. Many other areas prohibit fires in certain zones. For example, Yosemite National Park prohibits fires above 9,600 ft (2 926 m) and Olympic National Park prohibits fires above 3,500 ft (1 060 m) on the west slope of the mountains and above 4,000 ft (1 220 m) on the east slope.

Although visitors in many areas oppose campfire prohibitions (Lucas 1980), in Mount McKinley National Park 69 percent of the respondents to a survey had no opposition to a proposed "no campfire" policy.[1] In 1978, 75 percent of the respondents in a user survey supported the prohibition that had been established (Womble 1979). In Yosemite National Park, Absher and Lee (1978) found that although visitors who camped close to trailheads disliked fire prohibitions, visitors to more remote sites favored them. A substantial number of visitors use gas-fueled stoves (Lucas 1980), so other areas might also find a surprising lack of opposition, particularly if opportunities to have campfires can be provided elsewhere, either through internal zoning or alternative backcountry areas.

Management personnel must inform users of a campfire prohibition and enforce it. Dissatisfaction can be greatly reduced if users know about the prohibition when planning their trip, and understand the reasons for the prohibition.

If campfires are to be allowed, the next step is to decide whether or not current impacts are unacceptable or are likely to become so in the foreseeable future. Impacts, whether ecological or esthetic, are unacceptable when they are inconsistent with management objectives such as maintaining the integrity of natural ecosystems and the quality of the visitor's backcountry experience. Unacceptable impacts are most likely to occur where use is high, wood is scarce, impacts are highly visible, and management objectives stress strict resource protection and an undisturbed landscape. Future impacts should also be considered and planned for.

[1]Buskirk, Steve. 1976. Unpublished data. Mount McKinley National Park, Alaska.

Where impacts are considered acceptable, no management actions are required but the situation should be periodically monitored. Currently, most areas that allow campfires (79 percent) place no restrictions on campfire use. Only the Park Service has restrictions in more than 50 percent of the areas which allow fire.

Of the areas that have no restrictions, 29 percent discourage the use of wood fires. Again, the Park Service takes a particularly strong management stance, discouraging the use of fire in 70 percent of the areas with no restrictions.

Where impacts are considered to be unacceptable, management action is required. A basic and extremely important choice must be made for each zone between (1) attempting to minimize the intensity (that is the degree or amount) of impact on all sites by dispersing use so that sites have time to recover between periods of use, or (2) attempting to minimize the number of sites with campfire impacts by concentrating use on as few sites as possible.

Although both strategies can be effectively employed in different parts of a backcountry area, the two strategies are basically in opposition; a compromise between the two, within a small area, is likely to be ineffective. If managers decide to minimize the number of impacted sites, it would also be desirable to reduce impacts on these sites. This does not minimize impacts on all sites, however, as impacts on the sites of concentrated use will still be substantial. Minimizing impacts on all sites will only be successful if use is distributed between a large number of sites. This will result in some impacts on many sites.

Although it might seem desirable to have a moderate number of moderately impacted sites, this situation is usually unattainable because once use of campsites exceeds very low levels, near-maximum levels of impact occur (Wagar 1964; Fichtler 1980; Cole 1981). Total impacts can be most effectively minimized by managing for either a large number of lightly impacted sites (dispersal) or a small number of heavily impacted sites (concentration).

## The Dispersal Strategy

Dispersal is a rest-rotation strategy in which use is so dispersed that individual sites have time to fully recover from firewood collection and burning before being used again. In this way large numbers of sites are impacted, but impacts are relatively minor and are not cumulative. The problem is insuring that impacts remain minor and that use is infrequent enough so that sites are not reused before they have had time to recover.

Only the Forest Service consciously attempts the dispersal strategy; 16 percent of the Forest Service areas that allow fire encourage visitors to use previously unused sites. However, many other areas promote this strategy—perhaps unconsciously—by scattering all fire rings, even on consistently used sites.

Dispersal is most appropriate in zones or areas in which use levels are low, attractions are scattered, and potential campsites are numerous. It is likely to be ineffective in areas that are relatively heavily used because campsite use is likely to occur too frequently to allow full recovery. Even if use levels are low, this strategy is inappropriate where the number of potential or desirable campsites is limited. It will also be ineffective in areas used by novices or visitors who have not been adequately exposed to minimum-impact camping techniques, and in areas without sufficient funding or staff to adequately educate visitors.

### MANAGEMENT PRESCRIPTION

Two management actions are absolutely necessary to make dispersal work. Visitors must be highly educated in minimum-impact camping techniques, and they must be dispersed widely enough so they do not camp on previously used sites. Both of these are necessary. Visitors must be educated **before** use dispersal is attempted. Otherwise, impacts will be spread throughout the area.

Both actions are difficult. Most attempts to voluntarily disperse use have met with rather limited success (Schomaker 1975; Lucas 1981), although Krumpe (1979) describes a technique that was successful in Yellowstone National Park. If visitors will not voluntarily disperse, then rationing by trailhead or travel zone is likely to be the most effective course of action. Once this is accomplished, however, it may be even more difficult to get people to use previously unused sites. In a study in Great Gulf Wilderness, N.H., for example, Canon and others (1979) found that all campers used previously used sites despite being asked "not to camp at sites that show clear signs of previous use."

At this time we do not know how long recovery periods should be. Undoubtedly, this varies greatly between ecosystems. In subalpine forests it appears that use of the same site once a year probably does not insure full recovery (Cole 1981). Therefore, until more accurate estimates of recovery rates are available for more ecosystem types, it would be prudent to keep occupancy frequencies to less than one night per year.

Minimum-impact campfire use and camping techniques are of the utmost importance. (Guidelines for establishing an educational program and suggested practices are discussed in detail in a subsequent section) No evidence of previous use should be left; otherwise, too much repeat use will occur.

### SUPPORTING MANAGEMENT ACTIONS

Necessary supporting actions include (1) impact monitoring, (2) rehabilitation of impacted sites, and (3) enforcement. If visitors are poorly educated in minimum-impact camping techniques, or if use levels are too high, impacted sites will start appearing throughout the area. Impact monitoring is needed to judge whether the strategy is working. A simple inventory of all evidence of human use (for example, fire rings, blackened rocks, charcoal, informal trails, and so on), noting type of impact and location, would probably be sufficient. Some examples of monitoring systems can be found in Frissell (1978), Shreiner and Moorhead (1979), and Parsons and MacLeod (1980). This inventory should be most intensive in the most heavily visited areas, but it should periodically cover the entire area.

Rehabilitation, which will be discussed in more detail later, is particularly important. All impacted sites need to be closed and rehabilitated so they do not encourage repeat use. All fire rings should be removed and all evidence of fire eliminated. Enforcement may also be necessary to keep visitors off impacted areas and to ensure the use of minimum-impact techniques. This can be costly because visitors are so widely dispersed. If enforcement becomes a problem, it might be worth reassessing the practicality of this management strategy. Any need for increased patroling and enforcement should be identified by the impact monitoring system.

### ADVANTAGES AND DISADVANTAGES

This strategy promotes the type of wilderness situation that most managers and many users probably equate with the "wilderness ideal"; evidence of human impact is minimal and crowding is generally avoided. Moreover, wood depletion should not be a problem because use levels are so low. Campfire impacts do occur, but the visitor usually does not notice them and they are never allowed to intensify.

This strategy is difficult to implement in many areas and has the potential for widespread damage if it fails. The key to this strategy is keeping impacts to a minimum on all sites. So many sites are impacted that if the intensity of impacts cannot be kept to a minimum, site impacts will proliferate.

Managers should be cautious about attempting dispersal, particularly in parts of backcountry areas that are frequently used. Where visitor concentrations are low in relation to potential campsites, however, and visitors are willing to disperse and practice low-impact camping techniques, dispersal could perpetuate an ideal low-density, low-impact wilderness atmosphere.

## The Concentration Strategy

Concentration recognizes that impacts are the inevitable result of use, and that total impacts can be minimized by confining impacts to as few sites as possible. Sites of concentrated use become substantially impacted, but most of the backcountry area remains unaffected by camping and campfires.

Currently, only 10 percent of the existing and proposed wilderness areas that permit fires have regulations that require visitors to camp on designated sites. Another 14 percent of the areas that permit campfires do not regulate use, but encourage visitors to camp on previously used sites. These areas have adopted the use concentration strategy. This strategy is particularly prevalent in the National Park Service; 57 percent of the areas that allow fires attempt to concentrate these impacts. This compares with 21 percent in the Forest Service, 6 percent in the Fish and Wildlife Service, and 9 percent in the Bureau of Land Management.

The concentration strategy is most appropriate in zones or areas in which the manager cannot insure against repetitive use of sites (areas that are heavily used or where potential campsites are limited). It is appropriate when visitors are not well educated in minimum-impact camping techniques. As the more conservative of the two strategies—the strategy less likely to cause widespread damage if ineffective—concentration is also appropriate in areas where the manager is unsure what to do. Finally, it is appropriate in areas of high fire danger.

Concentration is inappropriate in lightly used areas where wood is scarce because it leads unnecessarily to firewood depletion. In areas where wood supplies are meager and use levels are high, dispersal will not solve the problem either, and campfires should be prohibited. Concentration of campfires is also inappropriate in lightly used zones or areas that are managed to offer particularly high levels of solitude and naturalness.

### MANAGEMENT PRESCRIPTION

The major action required is to insure that all fires are built on designated or previously used sites. On each campsite a permanent fire site should be designated, whether it is a constructed fireplace or an officially sanctioned fire ring. This action will confine the effects of fire to a small area, although these fire sites will be highly altered by repeated burning.

The distribution of fire sites throughout the area can vary with management objectives. Clustered sites are easier to administer and patrol than more widely distributed designated sites. They reduce campsite solitude and compound some ecological problems, however, such as bear encounters, waste disposal, and depletion of local wood supplies.

Managers must also decide how many sites to have and whether a reservation system is necessary. In any local area there should be at least enough sites available to handle the maximum number of parties anticipated at one time. The number of sites necessary to accommodate a given amount of use is lowest with a reservation system because the need for "overflow" sites is eliminated. Nevertheless, the need to make reservations greatly reduces spontaneity and freedom, extremely important elements of a wilderness experience.

### SUPPORTING MANAGEMENT ACTIONS

Site maintenance and enforcement of camping regulations are extremely important actions. These sites will be frequently used, so they must remain clean and desirable. For example, litter, partially burned logs, charcoal, horse manure, and visitor-built "improvements" can make a campsite undesirable (Lee 1975). Although a visitor education program could minimize most of these problems, managers should patrol sites and clean up where necessary. Otherwise, visitors may start to camp offsite. If new fire rings are constructed by visitors, all rings but the officially sanctioned ring should be removed. Because the number of sites is minimized, patrol is less costly than in a dispersed situation.

The most significant management problems will probably be depletion of local wood supplies and illegal camping. Wood depletion problems could be reduced by encouraging visitors to use stoves for cooking, build small fires, and gather wood offsite; by distributing designated sites widely; and by locating sites in productive forests. If visitors respond to depletion by damaging standing trees, local campfire bans may be the only alternative.

Illegal campfires may result from general dissatisfaction with camping on previously used sites, dissatisfaction with specific campsite conditions, or insufficient available sites in a specific locality. General dissatisfaction can be alleviated by allowing offsite camping without fire, allowing dispersed campfires in other zones, or suggesting alternative areas with a dispersed program. Dissatisfaction with specific conditions can be reduced by providing more site information and increasing site maintenance. Solving problems of too few available sites will require either a reduction in use or an increase in the number of sites.

Minimum impact practices are less crucial than in areas practicing the dispersal strategy, but they can help to reduce impacts. The most important practices to teach include keeping fires small and of short duration, using small pieces of downed wood, and conscientious cleanup. Visitors should **not** destroy fire rings.

### ADVANTAGES AND DISADVANTAGES

The advantage of this strategy is that a large number of visitors will alter relatively few sites even if they know little about minimum-impact camping and even if few potential campsites exist. This strategy guarantees near pristine conditions throughout the vast majority of the area. This strategy also recognizes that the majority of visitors use the same few sites anyway.

The major disadvantage is that localized impacts are severe and are immediately obvious to the visitor. Although there is little to suggest that visitors are substantially bothered by these impacts, obvious impacts may result in less respect for a low-impact ethic. Tree damage, as wood supplies become depleted, may be a particularly troublesome example. The visitor also loses the freedom to choose a new fire site.

## MINIMUM-IMPACT CAMPFIRE TECHNIQUES

Educating users to practice minimum-impact techniques requires that managers implement programs to convince users of the **need** to use proper techniques and show users **which** techniques to use to meet management objectives for local areas and **how** to properly use those techniques. Appropriate techniques in one situation may be inappropriate in a different situation. The following discussion will focus first on some principles for establishing an education program and then address specific techniques that minimize campfire impact.

### Establishing an Educational Program

The following are some points to be considered when establishing a minimum-impact campfire program. Additional sources of information include Fazio (1979) and Bradley (1979).

1. Focus the message. Clearly state the problem and the minimum-impact techniques that would avoid the problem. The appropriateness of techniques will vary with management strategies.
2. Identify the audience. Concentrate your educational effort on the user groups that contribute most to the problem.
3. Decide where to contact the audience. Some visitors can be contacted at home, if they write for information. Local residents can be reached with special programs in the community or on radio and television; college students can be reached on campus. In most cases a large proportion of the visitors enter the wilderness at a few popular trailheads, so these are particularly efficient locations for contacting visitors. The most effective educational programs will attempt to contact different segments of their audience in several different locations, placing top priority on locations where "problem users" can be reached (Bradley 1979).
4. Select communication methods. Personal contact by trained staff and audiovisual programs have been particularly effective (Fazio 1979). Brochures are also effective, but are most useful if people have them in the planning stages of outings (Lime and Lucas 1977). Minimum-impact information is being included in guidebooks and how-to-do-it manuals, but a great deal more is needed. Mass media such as television and newspapers have potential, but failed to reach the right audience in one test (Fazio 1979). Demonstrations and field programs that

show how to use techniques can be used in town or at popular trailheads. Again, a variety of media tailored for the appropriate audience and directed toward users in town, at trailheads, and within the wilderness will be most successful.

5. Monitor education success. Some system of gaging how well objectives are being met is necessary so that time and money are not wasted and so that programs can be improved. This can be tied into monitoring campfire impacts and the incidence of noncompliance with rules and regulations.

## Techniques

Although impact will not be eliminated if a fire is built, it can be reduced depending on which techniques are used and how carefully they are applied. **Note that recommendations for areas concentrating campfires differ from those for areas attempting dispersal.** Four topics will be discussed: location of fire sites, construction, fuel collection and burning, and cleanup.

**Location** (applicable only in areas of dispersed campfires):

1. Avoid sites that appear to have been previously used—those with trampled plants, litter or charcoal, sooty rocks, or disturbed soil. Limit stay to one night if trampling or other evidence of human use begins to show.
2. Try to find an area with as little natural vegetation as possible. River bars, beaches, and rocky areas are good sites for fires if cleaned afterwards.
3. Consider wildfire safety but avoid clearing a large area of combustible material. Where fire danger exists use fire pans, existing bare ground, or do not build a fire.

**Construction** (applicable only in areas of dispersed campfires, listed in order of preference):

1. *Fire pan*: Building the fire in a fire pan made of any convenient fireproof material is the most effective way to minimize impacts (fig. 10). Ideally, pans should have legs or some other means to support the pan at least 6 inches (15 cm) above the ground. Otherwise, the ground will be scorched.

**Figure 10.—Collapsible, lightweight (24-ounce [680-g]) grill makes an inexpensive fire pan.**

2. *Bare mineral soil*: Where there is bare mineral soil, such as sandy or rocky areas, fires can be built directly on the soil. Avoid blackening rocks by cooking on a stove, using a grill with folding legs, or hanging pots from a dead branch. If it has not rained recently, soak the fire site prior to use. Soaking will reduce heat transfer into the soil, so less of the organic matter and soil biota will be destroyed.
3. *Litter and duff*: Where vegetation is sparse, but the mineral soil is covered by organic layers of twigs, needles, leaves, and products of their decomposition, build the fire in a pit excavated down to the gritty, lighter colored inorganic mineral soil.
4. *Flat rock*: A fire can be built on a large, flat rock covered with several inches of mineral soil. In many areas suitable rocks will not be available, so users should not count on using this technique.
5. *Dense vegetation*: Digging a pit may be the only possible technique in areas with a dense ground cover. This is a difficult technique, however, with a high potential for damage. Therefore, we do not think it should be widely recommended. If this method is used, a flat-bladed digging tool must be carried. Dig a pit as deep as the plant's roots, if possible. Remove the plants and soil in as large a block as possible and place them adjacent to the pit. This material should be kept moist. After cleaning up after the fire, the block of plants and soil should be carefully replaced, making sure there are no air pockets underneath or around the sides to cause drying of roots or subsequent settling of the soil. Water the site well to help the plants recover from any damage.

**Fuel use** (applicable to all fires):

1. Wood should be gathered only in areas where it is abundant. Some should always be left so the area does not look denuded.
2. Only dead and down-on-the-ground wood should be used. Never use standing trees or branches on standing trees. If a choice exists, softwood fuels are preferable to hardwoods as they transfer less heat into the soil (Fenn and others 1976).
3. The wood collected should be hand breakable and as dry as possible. Small pieces of dry wood are easiest to burn down to ash so that no charcoal is left. It is important to leave larger pieces of wood. Leaving the axe and saw at home lightens the load.
4. Take only as much wood as you will need; do not stockpile. This will reduce trampling and facilitate cleanup.
5. In foraging for firewood do not walk on areas that appear trampled. Disperse impact so that trails will not be formed.
6. Keep the fire small and of short duration to conserve wood for others. A small, brief fire will also cause less impact to the soil. Use a stove for cooking meals and a campfire for a short evening period or to dry clothing.
7. Food scraps and plastic are difficult to dispose of by burning. Complete combustion requires a hot fire, which wastes wood and transfers large amounts of heat into the soil. Incomplete combustion makes cleanup difficult. Foil, often used to line paper packets, does not burn.

**Cleanup** (steps 1-2 apply to all areas; steps 3-6 apply only to areas of dispersed use):

1. At least 30 minutes before finishing with the fire, begin to burn all remaining wood and charcoal to ash. Do not add more wood, except very small pieces that might be needed to help burn stubborn charcoal. Keep heaping the coals and unburned pieces into the center where the heat is greatest. Fan as needed to help combustion.
2. When only white ash remains, soak with water to be sure no live coals are left. Crush and grind any charcoal remnants to powder.
3. Scatter any excess firewood far from the site.
4. When you are certain that the fire is out—feel for live coals—scatter the ash widely in inconspicuous places (fig. 11).

**Figure 11.—Minimum-impact fire built on a sandy site where the potential for damage was low. Only small pieces of wood were used (a). After the wood was burned to ash, the ash was scattered and all evidence of use was easily eliminated (b).**

5. If rocks were used, replace them in their original locations and configurations, charcoal side down.

6. Mask any remaining signs of disturbance by filling in pits and spreading native material that most nearly matches the surroundings. Leaves, needles, small branches, and loose soil are some materials to use. Take small amounts of such material from widely scattered spots, so no place will look used.

## REHABILITATION OF CAMPFIRE SITES

Campfire sites may need rehabilitation wherever campfires are prohibited. If repetitive use of a site is undesirable, the entire campsite will need rehabilitation. In dispersed use areas rehabilitation will be necessary wherever camping or campfire impacts become obvious. Where the concentration strategy is practiced, only illegal fire sites will need rehabilitation work.

To rehabilitate a site, managers must first prevent reuse and additional damage to the site. Often it is also necessary to prepare the soil and reestablish vegetation cover. The following recommendations, developed primarily from work in the Pacific Northwest, stress key points in order of application. Other useful references on rehabilitation include Hartmann and Kester (1975), Miller and Miller (1977), and Cole and Schreiner (1981). Local extension agents, nurseries, colleges, and garden clubs can often provide additional information about soil and vegetation conditions and useful techniques.

### Preventing Reuse of a Site

Remove as much evidence of previous use as possible so others are not attracted to the site.

1. Eliminate the fire ring. If the holes from which the rocks came are evident, replace the rocks in their original positions. If the blackened parts of rocks are still conspicuous and the soot cannot be removed, the rocks should probably be hidden in an inconspicuous place. Cleaning sooty rocks is difficult but sometimes is successful with a stiff bristle or wire brush. Some success with alcohol and commercial fireplace cleaners has been reported, but others have had as much success with water.

2. Remove all trash, including small pieces of foil mixed in with the charcoal. If it is not possible to separate the trash—for example, melted plastic often makes a congealed mass of charcoal—then all of the material should be packed out (fig. 12).

3. Remove all surface charcoal and partly burned wood. Scatter this debris widely, far from the site.

4. Scatter any remaining firewood far from the site.

5. Remove or repair any other signs of use, such as makeshift seats, sticks cut for tent pegs, rock windbreaks, etc.

6. If a site continues to be used, it may also be necessary to discourage use by temporarily posting signs, cordoning the area off with string, using natural debris to block access trails, or embedding rocks or logs in the site to make it less attractive (fig. 13). If none of these actions are successful, consider designating the site as a legal fire site and allowing no dispersed fires in the vicinity.

**Figure 12.—Backcountry ranger cleaning up an old fire site.**

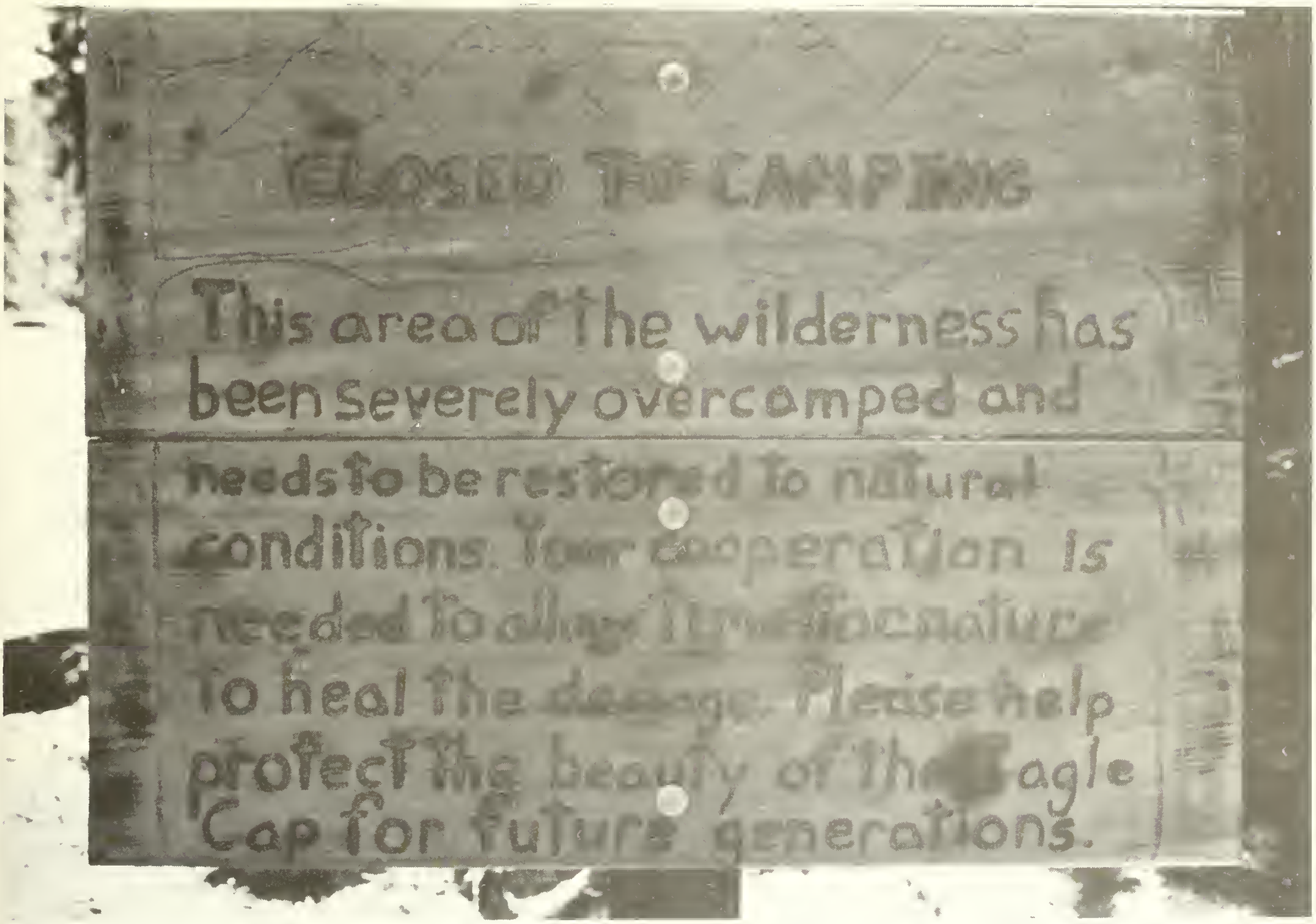


**Figure 13.—Signs may be necessary to prevent use of closed sites.**

## Preparing Soil

If the site was on a naturally bare area, or the bare ground of a designated or acceptable campsite, or was only used a few times, revegetation may not be necessary. In this case merely remove any debris and cover the fire site with a thin layer of mineral soil.

Where revegetation is desired, additional soil preparation will usually be helpful. Cultivate the surface soil to a depth of at least 4 inches (10 cm). Mix in locally collected decaying plant material or commercial peat moss. Fertilizer can also be added, although it has seldom significantly improved revegetation success in backcountry areas.

It is important to match soil amendments to the species to be planted. Campfires usually reduce soil acidity (Cole 1981); therefore, peat moss or raw organic matter should be added where the plants to be grown prefer acid soils. This applies to many of the species that inhabit higher elevation coniferous forests. Grasses prefer more neutral soils, however; so rehabilitation of grasslands would be facilitated by decreased acidity and acidic materials should not be added.

## Reestablishing Vegetation

Once a site has been cleaned and the soil prepared, one of several alternative revegetation methods may be applied. These include transpanting whole plants, plant cuttings, seeding, or merely facilitating natural revegetation. The use of cuttings is difficult and will not be discussed here. Readers are referred to Miller and Miller (1977) for more information.

### NATURAL REVEGETATION

Under some very favorable circumstances, natural revegetation may occur without much assistance within a few growing seasons. For example, nonforested sites with plentiful moisture and lush adjacent ground cover and sites where fires did not burn so hot and deep that organic matter and underground plant parts were completely destroyed may recover rapidly. On most sites unassisted revegetation will take decades (fig. 14). If site rehabilitation is an important element of a campfire or campsite management program, assisted revegetation should be tried if funding and manpower are available. (In many backcountry areas rehabilitation is done entirely by volunteers, which minimizes costs.)

### TRANSPLANTING

This is usually the quickest way to get plant cover on a site; but the technique is time consuming and disturbs adjacent areas from which plants are removed (fig. 15).

1. Select species adapted to grow on the site. Species that naturally colonize disturbed sites are good choices, as are plants that reproduce vegetatively. Obtain transplants from some distance away and, if several plants are needed, take them from scattered locations to disperse damage. Choose relatively short plants with healthy looking foliage.
2. Water both the plants to be transplanted and the area to be transplanted one day before transplanting.
3. Dig around the plant, vertically rather than in toward the plant, so roots are not damaged. If possible, excavate sections of

**Figure 14.—Little natural revegetation has taken place on this fire site (unused for 13 years) in Mt. Rainier National Park.**

turf, at least 8 inches (20 cm) in diameter, rather than individual plants. Lift the plant or turf out by supporting it under the root ball (roots and soil) rather than by pulling on the stem. Plant as soon as possible, being careful to always keep plants cool, moist, and out of direct sunlight.

4. Place the plant upright in a hole slightly larger than the root ball of the transplant. Make certain that roots are not doubled over upon themselves. Fill in the excess space with organic matter and soil. When tamped down firmly, the top of the root ball should be slightly below the ground surface to facilitate watering and to reduce the risk of damage from frost heaving.

5. Water thoroughly. If the weather is very warm, it may be necessary to water the plants daily or to shade them. Where this is not feasible, survival rates can be increased by pruning some flowers, leaves, and branch tips and by including large root balls.

6. Add a layer of mulch 0.5 to 1.5 inches (1 to 3 cm) thick over the transplanted area and around the base of the transplants. Alternative materials include leaves, pebbles, excelsior matting, jute netting, decaying wood, grass, or any other material that insulates yet allows free movement of air and moisture. Lightweight mulches that might blow away have to be anchored by limbs, stones, or similar objects.

7. Repair damage around the holes from which the transplants were taken. Fill the holes with soil and mulch the area.

**Figure 15.—A small warning sign and string boundary mark transplanted vegetation in Eagle Cap Wilderness, Oreg.**

**SEEDING**

In the Pacific Northwest, seeding is best done in the fall when seeds are naturally dispersing, but it can be done any time mature, viable seed is available.

1. Use seed from the same plant species as are found near the site. Ripe seeds can usually be shaken off plants. Be familiar with special germination requirements, such a scarification or stratification, of the species used.
2. Either scatter the seeds over the prepared soil bed and cover with about 0.5 inch (1 cm) of fine soil, or poke holes 0.5 inch (1 cm) deep, drop seeds in, and cover. Tamp the soil and mulch as described for transplanting.
3. Water, if seeding is done during or just prior to dry weather.

## Monitoring

Rehabilitation success can be greatly increased if records of work from a sample of sites are kept. Photographs, with date and treatment noted, may be sufficient, or more detailed field measurements can be taken. In the long run the time invested in testing can save a lot of wasted effort and unnecessary damage to resources.

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Discusses techniques for managing the ecological and esthetic impacts of backcountry campfires. Four sections cover the impacts of collecting and burning wood, management alternatives for various situations, minimum-impact campfire building, and rehabilitation of campfire sites.

KEYWORDS: backcountry management, campfires, recreational impacts

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# Understory-Overstory Vegetation Relationships: An Annotated Bibliography

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## RESEARCH SUMMARY

The purpose of this annotated bibliography is to provide a working tool for natural resource specialists and land-use planners attempting to (1) describe understory production, density, or composition associated with specific overstories, or (2) changes in understory characteristics resulting from conversion or modification of specific overstories. The annotations include identification of major overstory species if given, location of study areas if not included in the title, and form of data presentation.

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# Understory-Overstory Vegetation Relationships: An Annotated Bibliography

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## INTRODUCTION

This bibliography is an update, through 1979, of an earlier bibliography on understory-overstory vegetation relationships that contained references published through 1971.[1] As with the earlier version, the purpose of this bibliography is to provide a working tool for natural resource specialists and land-use planners attempting to describe (a) understory production, density, or composition associated with specific overstories, or (b) changes in understory characteristics resulting from conversion or modification of specific overstories.

The terms **understory** and **overstory**, as used in this bibliography, are somewhat arbitrary. To qualify for listing in the bibliography, a reference must present information on interactions in production, density, or composition between two distinct levels of vertical stratification within a vegetation community. References were avoided in which forest understories consisted primarily of young trees, and not of an obviously different life form such as shrubs or herbs.

References in this bibliography include popular and scientific publications that, in general, can be found in readily available sources. Only references presenting quantitative information (tables, graphs, equations, etc.) have been listed. The annotations include identification of major overstory plant species, if given, location of study areas, if not included in the title, and form of data presentation.

To facilitate use, the bibliography has been organized by 10 regional categories, as follows:

1. Alaska;
2. Pacific Northwest, including Washington and Oregon;
3. California;
4. Intermountain, including Nevada, Utah, and southern Idaho;
5. Northern, including northern Idaho, Montana, and North Dakota;
6. Rocky Mountain, including Wyoming, South Dakota, Nebraska, Colorado, and Kansas;
7. Southwestern, including Arizona and New Mexico;
8. Eastern, including Minnesota, Iowa, Missouri, Illinois, Wisconsin, Michigan, Indiana, Ohio, West Virginia, Maryland, Delaware, Pennsylvania, New Jersey, New York, Rhode Island, Connecticut, Massachusetts, New Hampshire, Vermont, and Maine;
9. Southern, including Kentucky, Virginia, Tennessee, North Carolina, South Carolina, Georgia, Alabama, Florida, Mississippi, Louisiana, Arkansas, Oklahoma, and Texas; and
10. Outside of the United States.

Boundaries of the first nine categories coincide (for the most part) with administrative regions of the USDA Forest Service (fig. 1).

An index of authors is included to assist in the use of the bibliography. This index, arranged alphabetically by authors' surnames, lists the references in the bibliography for each author and coauthor.

[1]Ffolliott, Peter F., and Warren P. Clary. 1972. A selected and annotated bibliography of understory-overstory vegetation relationships. Ariz. Agric. Exp. Stn., Tech. Bull. 198, 33 p.

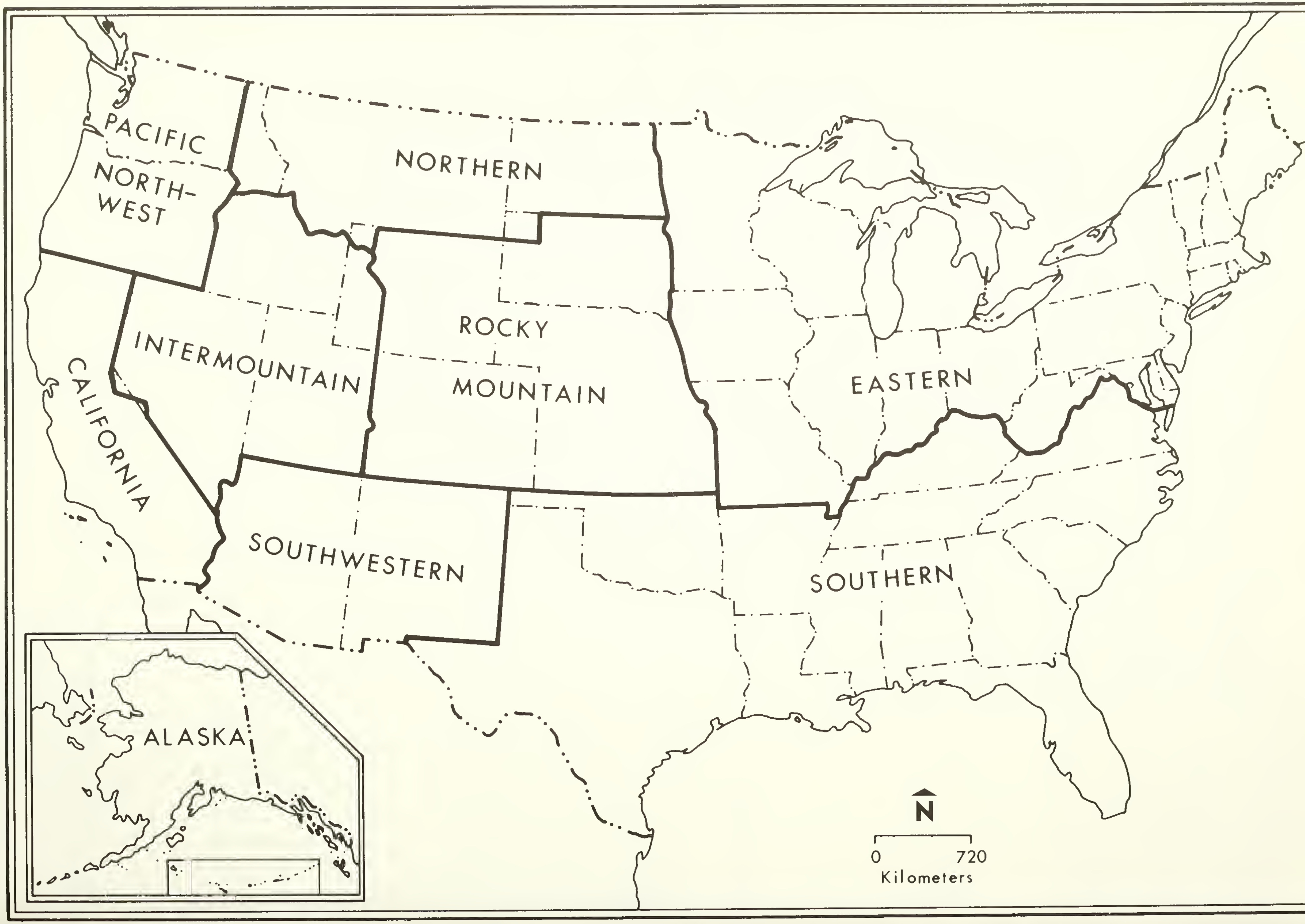


**Figure 1.—Boundaries of regional categories within the United States.**

## BIBLIOGRAPHY


### Alaska

1. BENNER, F. G., EDWARD C. CRAFTS, THEO C. HARTMAN, and LINCOLN ELLISON. 1938. A selected bibliography on management of western ranges, livestock, and wildlife. U.S. Dep. Agric. Misc. Publ. 281, 469 p.

Lists 8,274 publications through 1933 relating to grazing lands, domestic livestock, and wildlife production in Alaska and the 17 western states.

2. HARRIS, A. S. 1972. Natural reforestation after logging on Afognak Island. U.S. Dep. Agric. For. Serv., Res. Note PNW-176, 11 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Percent and height of ground cover on stocked and unstocked reforestation plots of sitka spruce (*Picea sitchensis*) 25 years after logging in Alaska are shown in tables.

### Pacific Northwest

3. BARRETT, JAMES W. 1965. Spacing and understory affect growth of ponderosa pine saplings. U.S. Dep. Agric. For. Serv., Res. Note PNW-27, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

The influence of the removal of understory vegetation on diameter and height increments of suppressed ponderosa pine (*Pinus ponderosa*) saplings after harvest of overstory in Oregon is graphically illustrated.

4. BARRETT, JAMES W. 1968. Response of ponderosa pine pole stands to thinning. U.S. Dep. Agric. For. Serv., Res. Note PNW-77, 11 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Three years after thinning ponderosa pine (*Pinus ponderosa*) overstories in north-central Washington, understory yield was greater on thinned than on unthinned plots.

5. BARRETT, JAMES W. 1970. Ponderosa pine saplings respond to control of spacing and understory vegetation. U.S. Dep. Agric. For. Serv., Res. Pap. PNW-106, 16 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

A tree spacing study in central Oregon showed that thinning ponderosa pine overstories will stimulate growth of understory vegetation, with greater amounts of understory vegetation at wider spacings. Data are graphically illustrated.

6. BARRETT, JAMES W. 1973. Latest results from the Pringle Falls ponderosa pine spacing study. U.S. Dep. Agric. For. Serv., Res. Note PNW-209, 21 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Percent of ground covered by understory vegetation for various densities of *Pinus ponderosa* is illustrated by tables and graphs.

7. BARRETT, JAMES W., and C. T. YOUNGBERG. 1965. Effect of tree spacing and understory vegetation on water use in a pumice soil. Soil Sci. Soc. Am. Proc. 29:472–475.

The effects of understory vegetation and forest stand density on growth (diameter) of ponderosa pine (*Pinus ponderosa*) are described for a study area in central Oregon.

8. BURKHARDT, J. WAYNE, and E. W. TISDALE. 1969. Natural and successional status of western juniper vegetation in Idaho. J. Range Manage. 22:264–270.

Foliage cover and density of woody understory vegetation are presented (table) for climax and seral stands of western juniper (*Juniperus occidentalis*).

9. COCHRAN, P. H. 1975. Response of pole-size lodgepole pine to fertilization. U.S. Dep. Agric. For. Serv., Res. Note PNW-274, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

On the Winema National Forest, Oreg., plots of *Pinus contorta* were fertilized with ammonium sulfate (21–0–0 24% S), nitrogen as urea, and treble superphosphate (0–45–0), and untreated. Grass production (dry weight, lb/acre) on controlled and treated plots are shown (tables).

10. CROUCH, GLENN L. 1968. Forage availability in relation to browsing of Douglas-fir seedlings by black-tailed deer. J. Wildl. Manage. 32:542–553.

Deer forage production associated with different plant communities common to northwestern Oregon is given in tabular form.

11. DEALY, J. EDWARD. 1966. Bitterbrush nutrition levels under natural and thinned ponderosa pine. U.S. Dep. Agric. For. Serv., Res. Note PNW-33, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Tables and graphs describing nutritional differences in antelope bitterbrush (*Purshia tridentata*) as influenced by different ponderosa pine (*Pinus ponderosa*) stocking levels are presented for a study area on the Pringle Falls Experimental Forest in central Oregon.

12. DEALY, J. EDWARD. 1971. Habitat characteristics of the Silver Lake mule deer range. U.S. Dep. Agric. For. Serv., Res. Pap. PNW-125, 99 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Understory and overstory cover and other information are presented for 21 tree- and shrub-dominated ecosystems in Lake County, Oreg.

13. DEALY, J. EDWARD. 1975. Management of lodgepole pine ecosystems for range and wildlife. *In* Manage. Lodgepole Pine Ecosystems, Symp. Proc. p. 556–568. Wash. State Univ., Pullman.

Understory response to a thinned lodgepole pine (*Pinus contorta*) stand in Oregon is graphically illustrated. Also, forage production as a result of lodgepole pine thinning in other States is described.

14. DEALY, J. EDWARD, J. MICHAEL GEIST, and RICHARD S. DRISCOLL. 1978. Communities of western juniper in the Intermountain Northwest. *In* Proc. Western Juniper Ecology and Manage. Workshop. p. 11–29. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. PNW-74. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Tabular data present the relation between *Juniperus occidentalis* percent cover and understory percent cover in central Oregon.

15. DEALY, J. EDWARD, J. MICHAEL GEIST, and RICHARD S. DRISCOLL. 1978. Western juniper communities on rangelands of the Pacific Northwest. *In* Proc. First Int. Rangeland Cong. p. 201–204. Denver, Colo.

Herbaceous cover and frequency data for various *Juniperus occidentalis* communities are given.

16. DRISCOLL, RICHARD S. 1964. Vegetation-soil units in the central Oregon juniper zone. U.S. Dep. Agric. For. Serv., Res. Pap. PNW-19, 60 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cover, constancy, basal area, and density data are presented for nine associations of *Juniperus occidentalis*.

17. DYRNESS, C. T. 1965. The effect of logging and slash burning on understory vegetation in the H. J. Andrews Experimental Forest. U.S. Dep. Agric. For. Serv., Res. Note PNW-31, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Tables and graphs describe understory plant cover before logging, after logging, and after slash burning on a study area in the western Cascades. The timber before logging was dominantly Douglas-fir (*Pseudotsuga menziesii*) mixed with varying amounts of western hemlock (*Tsuga heterophylla*).

18. DYRNESS, C. T. 1973. Early stages of plant succession following logging and burning in the western Cascades of Oregon. Ecology 54:57-69.

Changes in herbage production before logging, the first year after logging, and 5 years after slash burning *Pseudotsuga menziesii* on the H. J. Andrews Experimental Forest are given. Percent cover and frequency of plant species for 7 consecutive years are illustrated with tables and graphs.

19. EDGERTON, PAUL J. 1972. Big game use and habitat changes in a recently logged mixed conifer forest in northeastern Oregon. *In* West Assoc. Game and Fish Comm., 52nd Annu. Conf. Proc. p. 239-246.

On the Hoodoo and Mottet study areas, forests (*Abies grandis, Pseudotsuga menziesii*, and *Larix occidentalis*) were clearcut (slash burned and unburned), partially cut, and uncut. Percent foliage cover 5 years after logging is graphically illustrated.

20. FONDA, R. W. 1974. Forest succession in relation to river terrace development in Olympic National Park, Wash. Ecology 55:927-942.

Four terrace levels of different ages in the floodway zone of the Hoh River were characterized. Percent cover and frequency of the understory vegetation of five forest communities (*Alnus rubra, Picea sitchensis-Tsuga heterophylla-Populus trichocarpa, Acer macrophyllum, Picea sitchensis-Tsuga heterophylla*, and *Tsuga heterophylla*) are given (table and graph).

21. FRANKLIN, JERRY F., and C. T. DYRNESS. 1973. Natural vegetation of Oregon and Washington. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. PNW-8, 417 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Major vegetational units of Oregon and Washington are described. Percent canopy coverage of species (grasses, forbs, and shrubs) for numerous plant communities is given (table).

22. HEADY, HAROLD F., and JAMES BARTOLOME. 1977. The Vale Rangeland Rehabilitation Program: the desert repaired in southeastern Oregon. U.S. Dep. Agric. For. Serv., Resour. Bull. PNW-70, 139 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Presents various information on relation of grass to *Artemisia* spp.

23. HEDRICK, D. W., D. N. HYDER, F. A. SNEVA, and C. E. POULTON. 1966. Ecological response of sagebrush-grass range in central Oregon to mechanical and chemical removal of *Artemisia*. Ecology 47:432-439.

Herbage yields before and after removal (rotobeating and spraying with 2,4-D) of sagebrush (*Artemisia tridentata*) overstory are graphically illustrated.

24. HYDER, DONALD N. 1954. Spray to control big sagebrush. Oreg. Agric. Exp. Stn., Corvallis, Bull. 538, 12 p.

Herbage production before and after chemical control (2,4-D) of sagebrush (*Artemisia tridentata*) is discussed.

25. HYDER, DONALD N., and FORREST A. SNEVA. 1956. Herbage response to sagebrush spraying. J. Range Manage. 9:34-38.

Grass and herbage yields are compared (table) among sprayed (2,4-D; 2,4,5-T), grubbed, and untreated areas of sagebrush (*Artemisia tridentata*) overstory in Oregon.

26. INGRAM, DOUGLAS C. 1931. Vegetative changes and grazing use on Douglas-fir cutover land. J. Agric. Res. 43:387-417.

Density of understory vegetation before and after cutting and burning Douglas-fir (*Pseudotsuga taxifolia*) overstory is given (table) for the Cascade Mountains in Oregon and Washington.

27. JACKSON, M. T., and ADOLPH FALLER. 1973. Structural analysis and dynamics of the plant communities of Wizard Island, Crater Lake National Park. Ecol. Monogr. 43:441-461.

Density values for the herbaceous species in the five major communities (cinder slope [*Polygonum newberryi-Eriogonum pyrolaefolium* var. *coryphaeum*], crater rim [*Pinus albicaulis*], lower cone [*Abies magnifica* var. *shastensis*], north slope [*Tsuga mertensiana*], and lava flow [*Tsuga mertensiana-Sambucus microbotrys*]) that comprise the study area are given (table).

28. LONG, JAMES N., and J. TURNER. 1975. Aboveground biomass of understory and overstory in age sequence of four Douglas-fir stands. J. Appl. Ecol. 12:179-188.

Above ground biomass for herbs and shrubs growing under *Pseudotsuga menziesii* of various ages (22, 30, 42, and 73 years) near the A. E. Thompson Research Center, Wash., is given (table).

29. McCONNELL, BURT R., and JUSTING. SMITH. 1965. Understory response three years after thinning pine. J. Range Manage. 18:129-132.

Linear prediction equations describe increase in yield of understory vegetation after thinning ponderosa pine (*Pinus ponderosa*) overstory as a function of residual growing area per tree, percent overstory canopy, and overstory density. The equations represent data from a study area in north-central Washington.

30. McCONNELL, BURT R., and JUSTIN G. SMITH. 1970. Response of understory vegetation to ponderosa pine thinning in eastern Washington. J. Range Manage. 23:208-212.

A curvilinear (positive) relationship between increase in yield of understory vegetation 8 years after thinning ponderosa pine (*Pinus ponderosa*) and residual tree spacing is described. Also, a linear (negative) relationship between increase in yield of understory vegetation and percent overstory canopy is given.

31. McCONNELL, BURT R., and JUSTING. SMITH. 1971. Effect of ponderosa pine needle litter on grass seedling survival. U.S. Dep. Agric. For. Serv., Res. Note PNW-155, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Density of hard fescue (*Festuca ovina*) under different levels of ponderosa pine (*Pinus ponderosa*) needle accumulation is illustrated (graph) for a study area in Washington.

32. MILLER, A. E. 1957. Sagebrush control. Soil Conserv. 23:18-19. Grass production with and without chemical control of sagebrush is given for the State of Washington.

33. MILLER, RICHARD F., and WILLIAM C. KRUEGER. 1976. Cattle use on summer foothill rangelands in northeastern Oregon. J. Range Manage. 29:367–371.
Herbage production under different overstory canopy covers in the Wallowa Mountains is discussed and linear coefficients of determination are given. Tree species are ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and grand fir (*Abies grandis*).

34. MOIR, WILLIAM H. 1966. Influence of ponderosa pine on herbaceous vegetation. Ecology 47:1045–1048.
In Washington, field and experimental data presented (tables and graphs) suggest that ponderosa pine (*Pinus ponderosa*) developed past the seedling stage suppresses herbaceous vegetation.

35. NEILAND, BONITA J. 1958. Forest and adjacent burn in the Tillamook burn area of northwestern Oregon. Ecology 39:660–671.
The composition of herbaceous vegetation is presented (tables) for burned and unburned coniferous forests in the Oregon Coast Range. Dominant overstory species include Douglas-fir (*Pseudotsuga taxifolia*), western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), and various true firs (*Abies* spp).

36. RITTENHOUSE, L. R., and F. A. SNEVA. 1976. Expressing the competitive relationship between Wyoming big sagebrush and crested wheatgrass. J. Range Manage. 29:326–327.
Linear regression was used to express the relation between grass production and crown cover of *Artemisia tridentata* on the Squaw Butte Experiment Station, Oreg.

37. RUMMELL, ROBERT S. 1951. Some effects of livestock grazing on ponderosa pine forest and range in central Washington. Ecology 32:594–607.
Average densities of herbaceous vegetation are described (table and graph) for open ponderosa pine (*Pinus ponderosa*), mixed ponderosa pine—Douglas-fir (*Pseudotsuga taxifolia*), and grassland vegetative types.

38. SASSAMAN, ROBERT W., JAMES W. BARRETT, and JUSTIN G. SMITH. 1973. Economics of thinning stagnated ponderosa pine sapling stands in the pine-grass areas of central Washington. U.S. Dep. Agric. For. Serv., Res. Pap. PNW-144, 17 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
Ponderosa pine (*Pinus ponderosa*) stands were thinned to assess the effects of treatments upon the economic returns. Percent of composition of grasses, forbs, and shrubs after thinning is tabulated.

39. SHERMAN, ROBERT J., and WILLIAM W. CHILCOTE. 1972. Spatial and chronological patterns of *Purshia tridentata* as influenced by *Pinus ponderosa*. Ecology 53:294–298.
Between Suttle Lake and Sisters, Oreg., 10 plots, each consisting of a single ponderosa pine tree and surrounding antelope bitterbrush, were selected to compare *Purshia* resprouting and repopulation 23 to 106 years following fire (no fire on one plot). *Purshia* density, number of plants per clump, and percentage clumping for each plot are tabulated.

40. SKOVLIN, JON M., ROBERT W. HARRIS, GERALD S. STRICKLER, and GEORGE A. GARRISON. 1976. Effects of cattle grazing methods on ponderosa pine-bunchgrass range in the Pacific Northwest. U.S. Dep. Agric. For. Serv., Tech. Bull. 1531, 40 p. Washington, D.C.
The relation between *Pinus ponderosa* canopy cover and understory herbage production is described for the Blue Mountains of northeastern Oregon and southeastern Washington.

41. SNEVA, FORREST A. 1972. Grazing return following sagebrush control in eastern Oregon. J. Range Manage. 25:174-178.
On the Squaw Butte Experiment Station, *Artemisia tridentata* was treated with 2,4-D. Herbage yields following treatment are presented graphically.

42. STRICKLER, GERALD S. 1965. Soil and vegetation on the Starkey Experimental Forest and Range. Proc. Soc. Am. For. 1965:27–30.
Herbage production values are given for grassland and open *Pinus ponderosa* and *Pseudotsuga menziesii* stands in eastern Oregon.

43. STUTH, JERRY W., and A. H. WINWARD. 1976. Logging impacts on bitterbrush lodgepole pine-pumice region of central Oregon. J. Range Manage. 29:453–456.
Shrub and herbaceous production for unlogged and logged conditions is tabulated. Overstory is predominantly *Pinus contorta*.

44. TIEDEMANN, ARTHUR R., and GLEN O. KLOCK. 1973. First-year vegetation after fire, reseeding, and fertilization on the Entiat Experimental Forest. U.S. Dep. Agric. For. Serv., Res. Note PNW-195, 23 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
Following a severe burn of ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) dominants, four watersheds were treated differently: seeded and fertilized with 54 kg/ha of N as urea; seeded and fertilized with 57 kg/ha of N as ammonium sulfate; seeded only; and untreated. Cover and frequency of understory vegetation following treatments are given (tables and graphs).

45. WILLIAMSON, RICHARD L., and ROBERT H. RUTH. 1976. Results of shelterwood cutting in western hemlock. U.S. Dep. Agric. For. Serv., Res. Pap. PNW-201, 25 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
A three-stage shelterwood harvesting system establishing 12 densities of western hemlock (*Tsuga heterophylla*) on the Hemlock Experimental Forest was studied. The influence of time since cutting on the percent canopy coverage of herbs and shrubs is graphically illustrated.

46. YOUNG, J. A., D. W. HEDRICK, and R. F. KENISTON. 1967. Forest cover and logging: herbage and browse production in mixed coniferous forest of northeastern Oregon. J. For. 65:807–813.
Herbage and browse production under overstory cover classes is given in a table. Mixed coniferous overstory is predominantly grand fir (*Abies grandis*), Douglas-fir (*Pseudotsuga menziesii*), and western larch (*Larix occidentalis*).

47. ZOBEL, DONALD B., ARTHUR McKEE, GLENN M. HAWK, and C. T. DYRNESS. 1976. Relationships of environment to composition, structure, and diversity of forest communities of the central western Cascades of Oregon. Ecol. Monogr. 46:135–156.

The percent cover of shrubs and herbs for communities in three vegetation zones (*Tsuga heterophylla*, *Abies amabilis*, and a transition zone) is given (table).

## California

48. ADAMS, LOWELL, and DAVID J. DUNAWAY. 1960. The effect of timber overstory on deer habitat in mixed conifer type. U.S. Dep. Agric. For. Serv., Res. Note PSW–158, 2 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

A logarithmic relationship between understory and overstory densities is graphically illustrated for a study area on the west slope of the Sierra Nevada in California.

49. AGEE, JAMES K., and HAROLD H. BISWELL. 1970. Some effects of thinning on ponderosa pine and understory vegetation. J. For. 68:709–711.

Herbaceous vegetation production under thinned, fertilized ([NH4]2SO4), thinned and fertilized, and no treatment (control) stands of ponderosa pine (*Pinus ponderosa*) overstory in California is described.

50. CHABOT, BRIAN F., and W. D. BILLINGS. 1972. Origins and ecology of the Sierran alpine flora and vegetation. Ecol. Monogr. 42:163–199.

A transect from the desert near Bishop, Calif., to Piute Pass in the Sierra Nevada reveals four communities: desert shrub (*Ephedra nevadensis-Tetradymia spinosa*), open woodland (*Pinus monophylla-Artemisia tridentata*), open forest (*Pinus jeffreyi-Pinus murrayana*), and subalpine herbaceous vegetation (*Pinus albicaulis*). Percent cover of each species present at the four elevations is given (table).

51. CORNELIUS, DONALD R., and CHARLES H. GRAHAM. 1951. Selective herbicides for improving California forest ranges. J. Range Manage. 4:95–100.

Grass production under sprayed (2,4-D) and unsprayed sagebrush (*Artemisia tridentata*) is given for the ponderosa-Jeffrey pine forest zone of northeastern California.

52. GAYLORD, VERNON J., and STANLEY E. WESTFALL. 1971. Wedgeleaf ceanothus canopy does not affect total herbage yield. U.S. Dep. Agric. For. Serv., Res. Note PSW–253, 4 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Herbage yield associated with wedgeleaf ceanothus (*Ceanothus cuneatus*) overstory is presented (tables) for a study area on the San Joaquin Experimental Range in central California.

53. GORDON, DONALD T. 1962. Growth response of east side poles to removal of low vegetation. U.S. Dep. Agric. For. Serv., Res. Note PSW–209, 3 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Differences in growth of ponderosa and Jeffrey pine after removal of grasses, broad-leaved plants, and all understory vegetation are presented (tables) for a study area in northeastern California.

54. JOHNSON, WALTER, CYRUS M. McKELL, RAYMOND A. EVANS, and L. J. BERRY. 1959. Yield and quality of annual range forage following 2,4-D application on blue oak trees. J. Range Manage. 12:18–20.

Botanical composition, yield, percent crude protein, and percent phosphorus of herbage under treated (2,4-D) and untreated stands of blue oak (*Quercus douglasii*) are presented (tables) for the Sierra-Nevada foothills of California.

55. HANES, TED L., and HAROLD W. JONES. 1967. Postfire chaparral succession in southern California. Ecology 48:259–264.

Pre- and postfire vegetation are compared (table and graphs) for two chaparral stands in the San Gabriel Mountains.

56. MURPHY, ALFRED H., and BEECHER CRAMPTON. 1964. Quality and yield of forage as affected by chemical removal of blue oak (*Quercus douglasii*). J. Range Manage. 17:142–144.

Herbage yields under treated (2,4,-D) and untreated blue oak stands and in open areas are described for the grass-woodland cover type in California.

57. PERRY, CHESTER A., CYRUS M. McKELL, JOE R. GOODIN, and THOMAS M. LITTLE 1967. Chemical control of an old stand of chaparral to increase range productivity. J. Range Manage. 20:166–169.

Tables of grass production under sprayed (2,4-D; 2,4,5-T) and unsprayed stands of purple sage (*Salvia lencophylla*), chamise (*Adenostoma fasciculatum*), and California lilac (*Ceanothus* spp.) are presented for study sites in southern California.

58. RATLIFF, RAYMOND D., JACK N. REPPERT, and RICHARD J. McCONNEN. 1972. Rest rotation grazing at Harvey Valley: range health, cattle gains, costs. U.S. Dep. Agric. For. Serv., Res. Pap. PSW–77, 24 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

In the southern Cascades of California, two grazing treatments (rest-rotation and season long) were studied on plots dominated by silver sagebrush (*Artemisia cana*), black sagebrush (*A. arbuscula*), shorthair sedge (*Carex exserta*), ponderosa pine (*Pinus ponderosa*), and fir (*Abies* spp.). Herbage yield and percent cover of understory species for the two grazing treatments are given (tables).

59. SCHIMKE, HARRY E., LISLE E. GREEN, and DANNY HEAVILIN. 1970. Perennial grasses reduce woody plant seedlings on mixed conifer fuel-break. U.S. Dep. Agric. For. Serv., Res. Note PSW–203, 4 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Gives tabular data on relation of grass cover and density to growth of *Arctostaphylos viscida* seedlings in central California.

60. ST. ANDRE, G., H. A. MOONEY, and R. D. WRIGHT. 1965. The pinyon woodland zone in the White Mountains of California. Am. Midl. Nat. 73:225–239.

Understory (herbaceous and shrubby) cover and density are compared (table) to singleleaf pinyon (*Pinus monophylla*) overstory cover and density.

61. VOGL, RICHARD J. 1973. Ecology of knobcone pine in the Santa Ana Mountains, California. Ecol. Monogr. 43:125–143.

Average percent cover and number of plants per acre for species on unburned and burned knobcone pine (*Pinus attenuata*) stands is given (table).

62. VOGL, RICHARD J., and PAUL K. SCHORR. 1972. Fire and manzanita chaparral in the San Jacinto Mountains, California. Ecology 53:1179–1188.

In the California Peninsular Range Province, the floristic composition of plots dominated by *Arctostaphylos glandulosa* was changed following fire. Percent cover of herbaceous plants and grasses on plots 1 and 2 years following burning and on an unburned area are tabulated.

63. YOUNG, JAMES A., and RAYMOND A. EVANS. 1971. Medusahead invasion as influenced by herbicides and grazing on low sagebrush sites. J. Range Manage. 24:451–454.

In a low sagebrush (*Artemisia arbuscula*) community near Adin, Calif., both grazed and ungrazed plots were treated in one of three ways: application of 2,4-D, application of 2,4-D plus atrazine, and no application. Herbage yield, percent cover, and species composition (percent) for the six treatments are tabulated. Also, percent cover by year for grazed and ungrazed plots is given (graph).

## Intermountain

64. BARNEY, MILO H., and NEIL C. FRISCHKNECHT. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. J. Range Manage. 27:91–96.

Comparative changes of grasses, sagebrush (*Artemisia* spp.), and Utah juniper (*Juniperus osteosperma*) after fire are graphically illustrated.

65. BARTOS, DALE L. 1979. Effects of burning on the aspen ecosystem. *In* Wyoming Shrublands, Proc. Eighth Wyo. Shrub Ecol. Workshop. p. 47–58. Range Manage. Div., Univ. Wyo., Laramie.

Graphic presentation of understory response to burning of *Populus tremuloides* in Bridger-Teton National Forest.

66. BLACKBURN, WILBERT H., and PAUL T. TUELLER. 1970. Pinyon and juniper invasion in black sagebrush communities in east-central Nevada. Ecology 51:841–848.

Tabular and graphic information on understory frequency and cover are presented for *Pinus monophylla* and *Juniperus osteosperma* overstory.

67. BLAISDELL, JAMES P. 1949. Competition between sagebrush seedlings and reseeded grasses. Ecology 30:512–519.

Graphic and tabular data show relation between herbage yields and amount of *Artemisia tridentata* in Clark County, Idaho.

68. BLAISDELL, JAMES P. 1950. Effects of controlled burning on bitterbrush on the Upper Snake River Plains. U.S. Dep. Agric. For. Serv., Intermt. For. and Range Exp. Stn., Res. Pap. 20, 3 p. Ogden, Utah.

Tabular values are given for herbage production versus percent unburned *Purshia tridentata* in Idaho.

69. BLAISDELL, JAMES P. 1953. Ecological effects of planned burning of sagebrush-grass ranges on the Upper Snake River Plains. U.S. Dep. Agric., Tech. Bull. 1075, 39 p. Washington, D.C.

Herbage production in relation to different intensities of burning, including no burning, is given for big sagebrush (*Artemisia tridentata*) stands in Idaho.

70. BLEAK, A. T., and WARREN G. MILLER. 1955. Sagebrush seedling production as related to time of mechanical eradication. J. Range Manage. 27:91–96.

For Humboldt County, Nev., number of *Artemisia tridentata* plants present after attempted eradication and the number of crested wheatgrass seedlings are tabulated.

71. BRITTON, CARLTON M., and MICHAEL H. RALPHS. 1979. Use of fire as a management tool in sagebrush ecosystems. *In* The sagebrush ecosystem: a symposium [April 1978]. p. 101–109. Utah State Univ., College Nat. Resour., Logan.

Provides an hypothetical graphic relation between herbaceous fuel and *Artemisia* canopy cover for the western United States.

72. BROWN, JAMES K. 1974. Reducing fire potential in lodgepole pine by increasing timber utilization. U.S. Dep. Agric. For. Serv., Res. Note INT-181, 6 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

On the Teton National Forest, lodgepole pine (*Pinus contorta*) was clearcut and logged to near-complete and conventional utilization standards to assess the difference in fire potential for the two treatments. The percent cover of grass before and after near-complete and conventional utilization is tabulated.

73. COLLINS, WILLIAM B., PHILIP J. URNESS, and DENNIS D. AUSTIN. 1978. Elk diets and activities on different lodgepole pine habitat segments. J. Wildl. Manage. 42:799–810.

Herbage characteristics with and without *Pinus contorta* forest overstories are presented in tabular form for a study area in northeastern Utah.

74. COOK, C. WAYNE. 1958. Sagebrush eradication and broadcast seeding. Utah Agric. Exp. Stn. Bull. 404, 23 p.

Regression coefficients are given relating grass production to percent *Artemisia tridentata* cover and density in central Utah.

75. COOK, C. WAYNE. 1966. Development and use of foothill ranges in Utah. Utah Agric. Exp. Stn. Bull. 461, 47 p.

Tabular data are presented comparing grass production on native untreated areas and areas with control of *Artemisia tridentata* and seeding to exotic grasses.

76. COOK, C. WAYNE, and CLIFFORD E. LEWIS. 1963. Competition between big sagebrush and seeded grasses on foothill ranges in Utah. J. Range Manage. 16:245–250.

Seeded grass production is presented (table) for sprayed (2,4-D) and unsprayed areas of big sagebrush (*Artemisia tridentata*).

77. DESCHAMP, JOSEPH A., PHILIP J. URNESS, and DENNIS D. AUSTIN. 1979. Summer diets of mule deer from lodgepole pine habitats. J. Wildl. Manage. 43:154–161.

Understory information for different segments of a *Pinus contorta* forest in Utah is presented in tabular and graphic forms.

78. DWYER, DON D. 1975. Response of livestock forage to manipulation of the pinyon-juniper ecosystem. *In* The pinyon-juniper ecosystem: a symposium [May 1975]. p. 97–103. Utah State Univ., Coll. Nat. Resour., Logan.

Provides a summary of several studies that document the effect of pinyon-juniper stands on forage production in the West.

79. ECKERT, RICHARD E., JR., ALLEN D. BRUNER, and GERALD J. KLOMP. 1972. Response of understory species following herbicidal control of low sagebrush. J. Range Manage. 25:280–285.
Increases in herbage yields were studied in northern Nevada following the removal of *Artemisia arbuscula* and *A. longiloba*. Differences in yield are shown in graphic form; site-affected response is also discussed.

80. ELLISON, LINCOLN, and WALTER R. HOUSTON. 1958. Production of herbaceous vegetation in openings and under canopies of western aspen. Ecology 39:337–345.
Production of different artificially seeded herbaceous species under aspen (*Populus tremuloides*) canopies and in openings is given (tables) for a study area in central Utah.

81. EVANS, RAYMOND A., and JAMES A. YOUNG. 1975. Aerial application of 2,4-D plus picloram for green rabbitbrush control. J. Range Manage. 28:315–318.
Tabulations compare herbage yields with and without chemical control of *Chrysothamnus viscidiflorus* near Reno, Nev.

82. EVANS, RAYMOND A., and JAMES A. YOUNG. 1978. Effectiveness of rehabilitation practices following wildfire in a degraded big sagebrush-downy brome community. J. Range Manage. 31:185–188.
Benefits of chemically controlling *Chrysothamnus viscidiflorus* and *Tetradymia canescens* following wildfire in *Artemisia tridentata* grasslands were studied in western Nevada. Density of understory plants is given in tabular form.

83. FRISCHKNECHT, NEIL C. 1963. Contrasting effects of big sagebrush and rubber rabbitbrush on production of crested wheatgrass. J. Range Manage. 16:70–74.
Grass production on study plots with and without big sagebrush (*Artemisia tridentata*) and rubber rabbitbrush (*Chrysothamnus nauseosus*) is described for the Benmore Experimental Range in west-central Utah.

84. GREENWOOD, LARRY R., and JACK D. BROTHERSON. 1978. Ecological relationships between pinyon-juniper and true mountain mahogany stands in the Uintah Basin, Utah. J. Range Manage. 31:164–167.
The frequencies of various understory species are given for sites dominated by *Cercocarpus montanus, Pinus edulis*, and *Juniperus osteosperma*.

85. HARNISS, ROY O., and ROBERT B. MURRAY. 1973. Thirty years of vegetal change following burning of sagebrush-grass range. J. Range Manage. 26:322–325.
Total grass production was studied as an *Artemisia tridentata* range recovered after burning in Upper Snake River Plains of Idaho. Changes over time are presented in graphs and tables.

86. HULL, A. C., JR., and G. J. KLOMP. 1974. Yield of crested wheatgrass under four densities of big sagebrush in southern Idaho. U.S. Dep. Agric. For. Serv. Tech. Bull. 1483, 38 p.
Tabular and graphic data are presented on the relation of percent removal of big sagebrush and the resulting grass production per acre.

87. JENSEN, NEIL E. 1972. Pinyon-juniper woodland management for multiple use benefits. J. Range Manage. 25:231–234.
The effects of singleleaf pinyon (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*) removal (pruning, thinning, and weeding) on antelope bitterbrush (*Purshia tridentata*) and on herbage production on the Toiyabe National Forest, Nev., are discussed.

88. LAYCOCK, WILLIAM A., and THOMAS A. PHILLIPS. 1968. Long-term effects of 2,4-D on lanceleaf rabbitbrush and associated species. J. Range Manage. 21:90–93.
In Nevada, herbage yields on sprayed (2,4-D) and unsprayed areas supporting lanceleaf rabbitbrush (*Chrysothamnus viscidiflorus*) overstory are given in tabular form.

89. LORD, PHILIP B., and WILLIAM H. SANDERSON. 1962. An eastside Sierra Nevada aerial spraying project. J. Range Manage. 15:200–201.
Plant frequency of herbaceous plants and shrubs is given before and after spraying (2,4-D) the overstory of big sagebrush (*Artemisia tridentata*), black sagebrush (*A. arbuscula*), and antelope bitterbrush (*Purshia tridentata*).

90. MARSTON, RICHARD B., and ODELL JULANDER. 1961. Plant cover reductions by pocket gophers following experimental removal of aspen from a watershed area in Utah. J. For. 59:100–102.
A table presents the increase in herbaceous ground cover before and after aspen (*Populus tremuloides*) removal.

91. MUEGGLER, WALTER F. 1950. Effects of spring and fall grazing by sheep on vegetation of the Upper Snake River Plains. J. Range Manage. 3:308–315.
Cover and production for *Artemisia tripartita* overstory and herbaceous understory are presented in tabular form for Idaho.

92. MUEGGLER, WALTER F., and JAMES P. BLAISDELL. 1958. Effects on associated species of burning, rotobeating, spraying, and railing sagebrush. J. Range Manage. 11:61–66.
Herbage yields associated with untreated big sagebrush (*Artemisia tridentata*) overstory and with overstory reduced by various methods are presented in a graph and a table for a study area on the Upper Snake River Plains.

93. MUEGGLER, W. F., and D. L. BARTOS. 1977. Grindstone Flat and Big Flat exclosures: a 41 year record of changes in clearcut aspen communities. U.S. Dep. Agric. For. Serv., Res. Pap. INT-195, 16 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
The effects of aspen (*Populus tremuloides*) cutting on sprout, shrub, and herbage production in old exclosures in southeastern Utah are displayed in tabular form.

94. NIELSEN, DARWIN B., and STAN D. HINCKLEY. 1975. Economic and environmental impacts of sagebrush control on Utah's rangelands—a review and analysis. Utah Agric. Exp. Stn., Logan, Res. Rep. 25, 27 p.
Summarizes data on forage production with and without control of sagebrush.

95. ORR, HOWARD K. 1957. Effects of plowing and seeding on some forage production and hydrologic characteristics of a subalpine range in central Utah. U.S. Dep. Agric. For. Serv., Res. Pap. 47, 23 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Ground cover and forage production are given (tables) for treated (plowed and seeded) and untreated study plots on subalpine-herbaceous range. Overstory includes Engelmann spruce, alpine fir, and limber pine.
96. PATTEN, D. T. 1969. Succession from sagebrush to mixed conifer forest in the northern Rocky Mountains. Am. Midl. Nat. 82:229-240.
The frequency and aerial cover of herbaceous plants and shrubs, and the frequency, density, and basal area of young mixed conifers are described (table) in relation to sagebrush (*Artemisia tridentata*) and lodgepole pine (*Pinus contorta*) overstory conditions. The study site was in Yellowstone National Park.
97. PECHANEC, JOSEPH F., GEORGE STEWART, and JAMES P. BLAISDELL. 1954. Sagebrush burning: good and bad. U.S. Dep. Agric., Farmers' Bull. 1948, 34 p.
Herbage production on burned and unburned big sagebrush (*Artemisia tridentata*) ranges on the Upper Snake River Plains in Idaho is graphically illustrated.
98. PHILLIPS, T. A. 1977. An analysis of some Forest Service pinyon-juniper chaining projects in Region 4—1954-1975. U.S. Dep. Agric. For. Serv., Range Improve. Notes (Sept. 1977), p. 1-20. Intermt. Region, Ogden, Utah.
Data presented show an increase in forage production on a variety of sites in Utah and Nevada after pinyon-juniper removal.
99. PHILLIPS, T. A. 1979. North Cedars pinyon-juniper studies. U.S. Dep. Agric. For. Serv., Range Improve. Notes (Nov. 1979), p. 1-12. Intermt. Region, Ogden, Utah.
Tabular data are presented for grass, forb, and shrub production on chained and control *Pinus edulis-Juniperus osteosperma* areas in southern Utah.
100. RALPHS, MICHAEL H., and FRANK E. BUSBY. 1979. Prescribed burning: vegetation change, forage production, cost, and returns on six demonstration burns in Utah. J. Range Manage. 32:267-270.
Forage production is given in tabular form for burned and unburned *Artemisia tridentata*.
101. ROBERTSON, JOSEPH H. 1947. Response of range grasses to different intensities of competition with sagebrush (*Artemisia tridentata* Nutt.). Ecology 28:1-16.
Production of herbage per grass plant in relation to root competition from *Artemisia tridentata* in northern Nevada is graphically illustrated.
102. ROBERTSON, J. H. 1969. Yield of crested wheatgrass following release from sagebrush competition by 2,4-D. J. Range Manage. 22:287-288.
Yields of crested wheatgrass (*Agroypyron desertorum*) on sprayed (2,4-D) and unsprayed study plots with sagebrush (*Artemisia tridentata*) overstory are given for Nevada (table).
103. ROBERTSON, J. H. 1971. Changes on a sagebrush-grass range in Nevada ungrazed for 30 years. J. Range Manage. 24:297-400.
Annual production of forage grasses on planted and cleared, seeded ranges is given (table) for big sagebrush-Sandberg bluegrass (*Artemisia tridentata-Poa secunda*) type.
104. ROBERTSON, JOSEPH H. 1972. Competition between big sagebrush and crested wheatgrass. J. Range Manage. 25:156-157.
Mortality of *Artemisia tridentata* related to moisture competition with *Agropyron desertorum* is discussed for a study area in Nevada.
105. SCHUMAKER, GILBERT A., AND CLAYTON L. HANSON. 1977. Herbage response after mechanical and herbicide treatment of big sagebrush in southwest Idaho. U.S. Dep. Agric., Agric. Res. Serv. Publ. W-46, 15 p.
Tabular and graphic data are presented for treated and untreated *Artemisia tridentata*.
106. SMITH, ARTHUR D., PAUL A. LUCAS, CALVIN O. BAKER, AND GEORGE W. SCOTTER. 1972. The effects of deer and domestic livestock on aspen regeneration in Utah. Utah Div. Wildl. Resour., Salt Lake City, Publ. 72-1, 32 p.
Herbage production under different levels of mechanical control of *Populus tremuloides* is presented in tables.
107. TAUSCH, ROBIN J., and PAUL T. TUELLER. 1977. Plant succession following chaining of pinyon-juniper woodlands in eastern Nevada. J. Range Manage. 30:44-49.
The effect of *Pinus monophylla* and *Juniperus osteosperma* on herbaceous and shrubby cover is described (graph and equation).
108. VALLENTINE, JOHN F. 1971. Range development and improvements. 516 p. Brigham Young University Press, Provo, Utah.
Data from numerous studies (United States and Canada) of methods (mechanical, chemical, and burning) to increase herbage production on ranges characterized by various shrub overstories are discussed.
109. WARNER, JAMES H., and K. T. HARPER. 1972. Understory characteristics related to site quality for aspen in Utah. Brigham Young Univ. Sci. Bull. Biol. Ser. 16(2), 20 p. Provo, Utah.
Understory production and *Populus tremuloides* density are presented in tables.
110. WEST, NEIL E., ROBIN J. TAUSCH, and AGELI A. NABI. 1979. Patterns and rates of pinyon-juniper invasion and degree of suppression of understory vegetation in the Great Basin. U.S. Dep. Agric. For. Serv., Range Improve. Notes (Sept. 1979), p. 1-14. Intermt. Region, Ogden, Utah.
Presents a linear equation for the relation of understory cover to overstory cover for a site in southwestern Utah.
111. WRIGHT, HENRY A., LEON F. NEUNSCHWANDER, and CARLTON M. BRITTON. 1979. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities. A state-of-the-art review. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. INT-58, 48 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Various reports are cited that show how understory production is changed by removing *Artemisia* or *Pinus-Juniperus* by fire in western United States.
112. YOUNG, JAMES A., and RAYMOND A. EVANS. 1970. Invasion of medusahead into the Great Basin. Weed Sci. 18:89-97.
Cover, frequency, and constancy of herbaceous communities infested with medusahead (*Taeniatherum asperium*) under different woodland communities are given (tables). Woodland communities include low sagebrush-western juniper, big sagebrush-western juniper, and ponderosa pine.

113. YOUNG, JAMES A., and RAYMOND A. EVANS. 1976. Control of pinyon saplings with picloram or karbutilate. J. Range Manage. 29:144–147.
In Churchill Canyon, Nev., pinyon (*Pinus monophylla*) was controlled with herbicides. Herbage yields with and without trees are given in tabular form.
114. YOUNG, JAMES A., and RAYMOND A. EVANS. 1978. Population dynamics after wildfires in sagebrush grasslands. J. Range Manage. 31:283–289.
Response of understory species to burning of *Artemisia tridentata* was studied in western Nevada. Data are given in tabular and graphic forms.

## Northern

115. BASILE, JOSEPH V., and CHESTER E. JENSEN. 1971. Grazing potential on lodgepole pine clearcuts in Montana. U.S. Dep. Agric. For. Serv., Res. Pap. INT-98, 11 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Production of understory vegetation following clearing of lodgepole pine (*Pinus contorta*) is described by multiple regression sets that identify combinations of environmental factors affecting understory vegetation production.
116. HABECK, JAMES R. 1976. Forests, fuels and fire in the Selway-Bitterroot Wilderness, Idaho. *In* Proc. Tall Timbers Fire Ecol. Conf. and Fire and Land Manage. Symp. p. 305–353. Tall Timbers Res. Stn., Tallahassee, Fla.
Presents tabular understory and overstory cover data for mixed conifer forests.
117. HALL, DALE O., and JAMES D. CURTIS. 1970. Planting method affects height growth of ponderosa pine in central Idaho. U.S. Dep. Agric. For. Serv., Res. Note INT-125, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
The effect of understory removal (stripped, stripped and furrowed) on survival and growth (height) of planted ponderosa pine (*Pinus ponderosa*) is described (tables).
118. IRWIN, LARRY L., and JAMES M. PEEK. 1979. Shrub production and biomass trends following five logging treatments within the cedar-hemlock zone of northern Idaho. For. Sci. 25:415–426.
For *Thuja plicata, Abies grandis*, and *Tsuga heterophylla* habitat types equations are given which predict shrub biomass using environmental and some stand characteristics. Equations for the probability of shrub occurrence are also given.
119. KLEBENOW, DONALD A. 1965. A montane forest winter deer habitat in western Montana. J. Wildl. Manage. 29:27–33.
Browse production on five areas of varying densities of ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) in the Rattlesnake Creek Drainage, burned in 1919, is given (tables).
120. LOMMANSSON, T. 1948. Succession in sagebrush. J. Range Manage. 1:19–21.
The percent composition of grasses and grasslike plants, big sagebrush, and weeds, and the total vegetation cover are presented for a study area in southwestern Montana.
121. LYON, L. JACK and PETER F. STICKNEY. 1976. Early vegetal succession following large northern Rocky Mountain wildfires. *In* Proc. Tall Timbers Fire Ecol. Conf. and Fire and Land Manage. Symp. p. 355–375. Tall Timbers Res. Stn., Tallahassee, Fla.
Presents tabular data on overstory plant numbers and understory cover from Northern Rocky Mountain *Pinus* forests.
122. MACKIE, RICHARD J. 1970. Range ecology and relations of mule deer, elk and cattle in the Missouri River Breaks, Montana. Wildl. Monogr. 20, 79 p.
Tabular data on canopy coverage and frequency of occurrence for overstory and understory species within habitat types are given. The various habitat types have conifer, shrub, and herbaceous dominants.
123. MUEGGLER, WALTER F. 1965. Ecology of seral shrub communities in the cedar-hemlock zone of northern Idaho. Ecol. Monogr. 35:165–185.
Frequency, cover, and height are given in tabular form for understory species in relation to different amounts of *Thuja-Tsuga* disturbance.
124. PENGELLY, W. LESLIE. 1963. Timberlands and deer in the northern Rockies. J. For. 61:734–740.
Comparisons of ground cover and botanical composition of forage on logged and unlogged Douglas-fir (*Pseudotsuga menziesii*) forests in Idaho are presented (tables and graphs).
125. PFISTER, ROBERT D., BERNARD L. KOVALCHIK, STEPHEN F. ARNO, and RICHARD C. PRESBY. 1977. Forest habitat types of Montana. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. INT-34, 174 p.
Contains tables of overstory and understory canopy cover for 64 coniferous forest habitat types.
126. WEAVER, T., and D. DALE. 1974. *Pinus albicualis* in central Montana: environment, vegetation, and production. Am. Midl. Nat. 92:222–230.
Nineteen climax whitebark pine forests in the Rocky Mountains of south-central Montana were compared. Frequency of occurrence and percent cover of understory vegetation are given in tabular form for each of the forests. Forests varied in age, total cover, and basal area of the overstory species.

## Rocky Mountain

127. ALLEY, H. P., and D. W. BOHMONT. 1958. Big sagebrush control. Univ. Wyo. Agric. Exp. Stn. Bull. 354.
Grass cover related to *Artemisia tridentata* cover is presented graphically for Wyoming.
128. ALLEY, HAROLD P. 1956. Chemical control of big sagebrush and its effect upon production and utilization of native grass species. Weeds 4:164–173.
Production of native grasses associated with different levels of control (2,4-D; 2,4,5-T) of big sagebrush (*Artemisia tridentata*) is given (table) for a study area in northern Wyoming.
129. ARO, RICHARD S. 1971. Evaluation of pinyon-juniper conversion to grassland. J. Range Manage. 24:188–197.
Forage production with and without the application of different pinyon-juniper conversion techniques (burning, dozing, and chaining) is described for public lands in Colorado, Utah, Arizona, and New Mexico.

130. BARTOS, DALE L. 1978. Modeling plant succession in aspen ecosystems. *In* Proc. First Int. Rangeland Cong. p. 208–211. Denver, Colo.

Biomass of understory and overstory is simulated through time for central Rocky Mountain ecosystems.

131. BROWN, HARRY E. 1958. Gambel oak in west-central Colorado. Ecology 39:317–327.

The occurrence, ground cover, and production of understory plants under Gambel oak (*Quercus gambelii*) overstory and in adjacent openings are given in tabular form.

132. CURRIE, PAT O. 1975. Grazing management of ponderosa pine-bunchgrass ranges of the central Rocky Mountains: the status of our knowledge. U.S. Dep. Agric. For. Serv., Res. Pap. RM–159, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Two- and three-dimensional graphs illustrate the relationship between herbage yields and timber (*Pinus ponderosa*) density, degrees of grazing use, and stocking rate.

133. DAVIS, JOSEPH H., III, and CHARLES D. BONHAM. 1979. Interference of sand sagebrush canopy with needle and thread. J. Range Manage. 32:384–386.

Effect of presence or absence of *Artemisia filifolia* on grass biomass is illustrated graphically for eastern Colorado.

134. DESPAIN, DON G. 1973. Vegetation of the Big Horn Mountains, Wyoming, in relation to substrate and climate. Ecol. Monogr. 43:329–355.

From the base of the range of the Big Horn Mountains to near timberline, four forest and shrub types (*Picea engelmannii-Abies lasiocarpa, Pinus contorta, Pseudotsuga menziesii*, and *Juniperus osteosperma*) were sampled. Percent cover of the herb layer in the forest communities is shown (graphs and tables).

135. GESINK, R. W., H. P. ALLEY, and G. A. LEE. 1973. Vegetation response to chemical control of broom snakeweed on a blue grama range. J. Range Manage. 26:139–143.

Herbage response to control (picloram and 2,4-D) of *Gutierrezia sarothrae* in southeastern Wyoming is presented graphically.

136. HOLCH, A. E. 1932. Forest vegetation in southeastern Nebraska. J. For. 30:72–74.

A census of trees, shrubs, and vines in three forest habitats is presented in tabular form. Habitats evaluated include basswood forest, red oak forest, and bur oak forest.

137. HULL, A. C., JR., N. A. KISSINGER, JR., and W. T. VAUGHN. 1952. Chemical control of big sagebrush in Wyoming. J. Range Manage. 5:398–402.

A table describes the relationship between grass production and sagebrush (*Artemisia tridentata*) kill (2,4-D; 2,4,5-T).

138. JEFFERIES, NED W. 1965. Herbage production on a Gambel oak range in southwestern Colorado. J. Range Manage. 18:212–213.

Herbage yields under an overstory of Gambel oak (*Quercus gambelii*) and in adjacent openings are given (table) for a study at the San Juan Experimental Station.

139. JOHNSON, W. M. 1953. Effect of grazing intensity upon vegetation and cattle gains on ponderosa pine-bunchgrass ranges of the front range of Colorado. U.S. Dep. Agric. Circ. 929, 36 p. Washington, D.C.

Herbage ground cover in grassland park, sparse ponderosa pine (*Pinus ponderosa*) overstory, dense ponderosa pine overstory, and abandoned field situations is presented in tabular form for a study on the Manitou Experimental Forest. Also includes a table of herbage production in grassland and open timber situations.

140 JOHNSON, W. M. 1969. Life expectancy of a sagebrush control in central Wyoming. J. Range Manage. 22:177–182.

Herbage production is given for areas with and without chemical control of *Artemisia tridentata*.

141. KISSINGER, N. A., JR., A. C. HULL, JR., and W. T. VAUGHN. 1952. Chemical control of big sagebrush in central Wyoming. U.S. Dep. Agric. For. Serv., Stn. Pap. 9, 14 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Grass production is compared (table) with percent big sagebrush (*Artemisia tridentata*) overstory killed (2,4-D; 2,4,5-T).

142. KISSINGER, N. A., JR., and RICHARD M. HURD. 1953. Control big sagebrush with chemicals and grow more grass. U.S. Dep. Agric. For. Serv., Stn. Pap. RM–11, 23 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Grass production under sprayed (2,4-D; 2,4,5-T) and unsprayed stands of big sagebrush (*Artemisia tridentata*) overstory is described for a study area in Wyoming.

143. KRANZ, JEREMIAH J., and RAYMOND L. LINDER. 1973. Value of Black Hills forest communities to deer and cattle. J. Range Manage. 26:263–265.

In South Dakota, studies were conducted of the relation of understory production to basal area of aspen (*Populus tremuloides*) and ponderosa pine (*Pinus ponderosa*). Data are presented graphically.

144. KRENZ, RONALD D. 1962. Costs and returns from spraying sagebrush with 2,4-D. Univ. Wyo., Laramie, Agric. Exp. Stn. Bull. 390, 31 p.

Values are tabulated for forage production with different degrees of chemical control of sagebrush in Wyoming.

145. KUFELD, ROLAND C. 1977. Improving Gambel oak ranges for elk and mule deer by spraying with 2,4,5-T. J. Range Manage. 30:53–57.

In northwestern Colorado, *Quercus gambelii* was removed by chemicals. Understory species abundance with and without spraying is presented in tabular f...

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150. PASE, CHARLES P. 1958. Herbage production and composition under immature ponderosa pine stands in the Black Hills. J. Range Manage. 11:238-243.
Herbage production under varying ponderosa pine (*Pinus ponderosa*) overstory densities is described in tables and graphs. Also, logarithmic prediction equations relating herbage production to different expressions of ponderosa pine density are given.

151. PASE, CHARLES P., and RICHARD M. HURD. 1957. Understory vegetation as related to basal area, crown cover, and litter produced by immature ponderosa pine stands in the Black Hills. Proc. Soc. Am. For. 1957:156-158.
Contains a logarithmic predicting equation describing herbage yields as a function of the density of ponderosa pine (*Pinus ponderosa*) overstory. Also, the curvilinear relationship illustrating the equation is given.

152. PAULSEN, HAROLD A., JR. 1969. Forage values of a mountain grassland-aspen range in western Colorado. J. Range Manage. 22:102-107.
Herbage production on grassland and *Populus tremuloides* ranges is given in tabular form.

153. PAULSEN, HAROLD A., JR., and JOHN C. MILLER. 1968. Control of Parry rabbitbrush on mountain grasslands of western Colorado. J. Range Manage. 21:175-177.
Grass and forb production under Parry rabbitbrush (*Chrysothamnus parryi*) stands treated with herbicides (2,4,-D, tordon) and under control stands is given in tabular form.

154. POND, FLOYD W., and DIXIE R. SMITH. 1971. Ecology and management of subalpine ranges on the Big Horn Mountains of Wyoming. Univ. Wyo., Laramie, Agric. Exp. Stn. Res. J. 53, 25 p.
A literature review, including a discussion of forage production as affected by control (herbicides) of big sagebrush (*Artemisia tridentata*) overstory, is presented.

155. REGELIN, WAYNE L., and OLAF C. WALLMO. 1978. Duration of deer forage benefits after clearcut logging of subalpine forest in Colorado. U.S. Dep. Agric. For. Serv., Res. Note RM-356, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Comparisons of understory production for uncut conditions and strip cuts in spruce, fir, and pine forests are given in tabular form.

156. REID, ELBERT H. 1965. Forage production in ponderosa pine forests. Proc. Soc. Am. For. 1964:61-64.
A literature review, including a summary of forage values and the influence of tree overstory on herbage production, is presented for the ponderosa pine forest type in the West.

157. SEVERSON, KEITH E., and CHARLES E. BOLT. 1977. Options for Black Hills forest owners: timber, forage, or both. Rangeman's J. 4:13-15.
In South Dakota, thinning of *Pinus ponderosa* affected understory characteristics. Data are presented in tabular form.

158. SEVERSON, KEITH E., and JEREMIAH J. KRANZ. 1976. Understory production not predictable from aspen basal area or density. U.S. Dep. Agric. For. Serv., Res. Note RM-314, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
A table showing the understory production under quaking aspen (*Populus tremuloides*) basal area levels ranging from 42 to 120 $ft^2$ per acre is given for the Black Hills and Bear Lodge Mountains.

159. SEVERSON, KEITH E., and JOHN F. THILENIUS. 1976. Classification of quaking aspen stands in the Black Hills and Bear Lodge Mountains. U.S. Dep. Agric. For. Serv., Res. Pap. RM-166, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Frequency, composition, productivity, and nutritive values of the understory under different *Populus tremuloides* canopy structures are presented for 28 stands in western South Dakota and northeastern Wyoming.

160. SHOWN, L. M., R. F. MILLER, and F. A. BRANSON. 1969. Sagebrush conversion to grassland as affected by precipitation, soil, and cultural practices. J. Range Manage. 22:303-311.
The yield of crested wheatgrass (*Agropyron desertorum*) is presented (table) for treated (plowing) and adjacent untreated areas of big sagebrush (*Artemisia tridentata*) in the West.

161. SMITH, DWIGHT R. 1967. Effects of cattle grazing on a ponderosa pine-bunchgrass range in Colorado. U.S. Dep. Agric. Tech. Bull. 1371, 60 p. Washington, D.C.
A graph describes herbage production under dense timber, open timber, and grassland situations on the Manitou Experimental Forest. The overstory is dominated by ponderosa pine (*Pinus ponderosa*).

162. TAYLOR, DALE L. 1973. Some ecological implications of forest fire control in Yellowstone National Park, Wyoming. Ecology 54:1394-1396.
Seven areas of *Pinus contorta* in Yellowstone National Park were selected to study changes in plant and animal diversity 1 to 300 years following fire. The number of species of herbs, shrubs, and trees for each area is given (tables).

163. THILENIUS, JOHN F., and GARY R. BROWN. 1974. Long-term effects of chemical control of big sagebrush. J. Range Manage. 27:223-224.
Effects of chemical control of *Artemisia tridentata* on herbage production in the Big Horn Mountains of Wyoming is discussed.

164. THOMPSON, WESLEY W., and F. ROBERT GARTNER. 1971. Native forage response to clearing low quality ponderosa pine. J. Range Manage. 24:272-277.
Forage production and species composition under ponderosa pine (*Pinus ponderosa*) overstory and on sites where ponderosa pine was removed (cutting) are described (tables) for different aspects on a study area in the Black Hills of South Dakota.

165. TURNER, GEORGE T. 1969. Responses of mountain grassland vegetation to gopher control, reduced grazing, and herbicide. J. Range Manage. 22:377-383.
Production of grasses, forbs, and shrubs is given (table) for sprayed (2,4-D) and unsprayed areas supporting silver sagebrush (*Artemisia cana*) in western Colorado.

166. TURNER, GEORGE T., and HAROLD A. PAULSEN, JR. 1976. Management of mountain grasslands in the central Rockies: the status of our knowledge. U.S. Dep. Agric. For. Serv., Res. Pap. RM-161, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
The effects of grazing treatments and various harvesting systems upon understory species on the spruce-fir (*Picea* spp. and *Abies* spp.) forests in Wyoming, Colorado, Arizona, and New Mexico are discussed (tables and graph).

167. WALLMO, OLAF C., WAYNE L. REGELIN, and DONALD W. REICHERT. 1972. Forage use by mule deer relative to logging in Colorado. J. Wildl. Manage. 36:1025–1033.

On the Fraser Experimental Forest, lodgepole pine (*Pinus contorta*) and spruce-fir (*Picea engelmannii-Abies lasiocarpa*) were logged and unlogged in alternate strips. The mean percentage frequencies of occurrence of herbage produced on the treated and untreated strips are compared (table).

168. WARD, A. LORIN. 1973. Sagebrush control with herbicide has little effect on elk calving behavior. U.S. Dep. Agric. For. Serv., Res. Note RM-240, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Changes in vegetation composition before and after spraying big sagebrush (*Artemisia tridentata*) on the Bighorn National Forest (Wyoming) with 2,4-D herbicide are given (table).

169. WILBERT, DON E. 1963. Some effects of chemical sagebrush control on elk distribution. J. Range Manage. 16:74–78. Tables describing grass, forbs, and brush production under sprayed (2,4-D) and unsprayed stands of big sagebrush (*Artemisia tridentata*) are presented for the Teton National Forest in Wyoming.

## Southwestern

170. ARNOLD, JOSEPH F. 1950. Changes in ponderosa pine bunchgrass ranges in northern Arizona resulting from pine regeneration and grazing. J. For. 48:118–126.

Tables and graphs describe relationships between herbaceous density and percent of ground covered by ponderosa pine overstory.

171. ARNOLD, JOSEPH F. 1953. Effect of heavy selection logging on herbaceous vegetation in a ponderosa pine forest in northern Arizona. J. For. 51:101–105.

Herbaceous density is presented (tables) before and after logging, and in terms of surface disturbances, slash accumulation, and change in canopy after logging.

172. ARNOLD, JOSEPH F. 1956. Conversion of poor and non-commercial pine stands to grasslands. *In* Recovering rainfall. p. 90–99. Dep. Agric. Econ., Univ. Ariz., Tucson.

Herbage yield before and after conversion (cutting, dozing, chopping) of ponderosa pine overstory is presented (table) for Arizona.

173. ARNOLD, JOSEPH F. 1956. Economic aspects of converting juniper and pinyon to grasslands. *In* Recovering rainfall. p. 67–89. Dep. Agric. Econ., Univ. Ariz., Tucson.

Herbage yield before and after conversion (dozing, chopping) of juniper and pinyon woodland overstories is presented (tables) for Arizona.

174. ARNOLD, JOSEPH F. 1964. Zonation of understory vegetation around a juniper tree. J. Range Manage. 17:41–42.

Herbage production is presented (table) by zones around a one-seed juniper (*Juniperus monosperma*) tree in a pinyon-juniper woodland of east-central Arizona.

175. ARNOLD, JOSEPH F., DONALD A. JAMESON, and ELBERT H. REID. 1964. The pinyon-juniper type of Arizona: effects of grazing, fire and tree control. U.S. Dep. Agric. Prod. Res. Rep. 84, 28 p. Washington, D.C.

Relationships between herbage cover and yield and percent canopy intercept of pinyon and juniper overstory are graphically illustrated. Overstory is dominated by Utah (*Juniperus osteosperma*), one-seed (*J. monosperma*), and alligator (*J. deppeana*) juniper.

176. ARNOLD, JOSEPH F., and W. L. SCHROEDER. 1955. Juniper control increases forage production on the Fort Apache Indian Reservation. U.S. Dep. Agric. For. Serv., Stn. Pap. 18, 35 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Tables and bar graphs describing understory yields before and after removal of one-seed juniper (*Juniperus monosperma*), other juniper, and pinyon (*Pinus edulis*) are presented for a study area in east-central Arizona. Also, relationships between herbage yields and overstory density are given.

177. BAKER, MALCHUS B., JR., and HARRY E. BROWN. 1974. Multiple use evaluations on ponderosa pine forest land. Annu. Ariz. Watershed Symp. Proc. 18:18–25.

Following thinning and clearing ponderosa pine (*Pinus ponderosa*) on the Beaver Creek Watershed, production of herbaceous and shrubby plants increased. The relationships between overstory removal and herbage production are graphically illustrated and described.

178. BISWELL, H. H. 1956. Manipulating plant cover on the Salt River watershed to increase water yield. *In* Recovering rainfall. p. 115–136. Dep. Agric. Econ., Univ. Ariz., Tucson.

Changes in forage production associated with different vegetation management practices are discussed for various overstory types (pinyon-juniper, ponderosa pine, aspen, spruce-fir, chaparral, and stream-course) in Arizona.

179. BRANSON, F. A., REUBEN F. MILLER, AND I. S. McQUEEN. 1976. Moisture relationships in twelve northern desert shrub communities near Grand Junction, Colorado. Ecology 57:1104–1124.

Contains table comparing percent cover of shrubs, grasses, and forbs for each of 12 communities: *Atriplex nuttallii, Hilaria jamesii-Atriplex confertifolia, Atriplex confertifolia, Atriplex corrugata, Artemisia tridentata, Chrysothamnus nauseosus, Chrysothamnus greenei, Eurotia lanata, Grayia spinosa, Tetradymia spinosa, Sarcobatus vermiculatus,* and *Elymus salinus.*

180. BROWN, HARRY E. 1965. Preliminary results of cabling Utah juniper, Beaver Creek watershed evaluation project. Annu. Ariz. Watershed Symp. Proc. 9:16–21.

Production of grasses, forbs, half-shrubs, and shrubs before and after mechanical removal of Utah juniper overstory in north-central Arizona is presented in tabular form.

181. BROWN, HARRY E. 1971. Evaluating watershed management alternatives. Am. Soc. Civil Eng., J. Irrig. and Drain. Div. 97 (IRl):93–108.

Changes in herbage production following implementation of different land management systems (clearing of timber overstories, reduction of timber overstory densities) are given (tables) for experimental sites in north-central Arizona. Vegetation types include pinyon-juniper woodland and ponderosa pine forest.

182. BROWN, HARRY E., MALCHUS B. BAKER, JR., JAMES J. ROGERS, and others. 1974. Opportunities for increasing water yields and other multiple use values on ponderosa pine forest lands. U.S. Dep. Agric. For. Serv., Res. Pap. RM-129, 36 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Data showing herbage production under different basal areas of *Pinus ponderosa* on the Beaver Creek watershed, Arizona, are listed in tabular form.

183. CABLE, DWIGHT R. 1957. Recovery of chaparral following burning and seeding in central Arizona. U.S. Dep. Agric. For. Serv., Res. Note 28, 6 p. Rocky Mt. For and Range Exp. Stn., Fort Collins, Colo.

Tables describing perennial grass basal density, estimated by line intercept, and shrub live oak (*Quercus turbinella*) crown density are given for a study area in the Pinal Mountains.

184. CABLE, DWIGHT R. 1967. Fire effects on semi-desert grasses and shrubs. J. Range Manage. 20:170-176.

On the Santa Rita Experimental Range, Ariz., velvet mesquite (*Prosopis juliflora*) was burned in one area and not burned on another area. Annual grass production before and after treatment was compared (graphs).

185. CABLE, DWIGHT R. 1969. Competition in the semidesert grass-shrub type as influenced by root systems, growth habits, and soil moisture extraction. Ecology 50:28-38.

Gives the relationship between production of perennial grass and burroweed (*Aplopappus tenuisectus*) crown cover (graph) for a study area on the Santa Rita Experimental Range in southern Arizona.

186. CABLE, DWIGHT R. 1971. Lehmann lovegrass on the Santa Rita Experimental Range, 1937-1968. J. Range Manage. 24:17-21.

The relation of native grasses and Lehmann lovegrass (*Eragrostis lehmanniana*) production to velvet mesquite (*Prosopis juliflora*) density and removal (2,4,5-T) is described for a study site in southern Arizona.

187. CABLE, DWIGHT R. 1972. Fourwing saltbush revegetation trials in southern Arizona. J. Range Manage. 25:150-153.

Effect of velvet mesquite (*Prosopis juliflora*), creosotebush (*Larrea tridentata*), and burroweed (*Aplopappus tenuisectus*) on survival of fourwing saltbush (*Atriplex canescens*) located on the Santa Rita Experimental Range is discussed. Creosotebush and mesquite-burroweed were sprayed with 4-amino-3,5,6 trichloropiclonic acid, grubbed, or untreated. Results are graphically illustrated.

188. CABLE, DWIGHT R. 1975. Influence of precipitation on perennial grass production in the semidesert Southwest. Ecology 56:981-986.

The amount of herbage produced (influenced by rainfall) on pastures on the Santa Rita Experimental Range having velvet mesquite (*Prosopis juliflora*) present and absent is graphically illustrated.

189. CABLE, DWIGHT R. 1975. Range management in the chaparral type and its ecological basis: the status of our knowledge. U.S. Dep. Agric. For. Serv., Res. Pap. RM-155, 30 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Production of grasses and forbs on Mingus Mountain, Ariz., during 5 consecutive years following burning of shrub live oak (*Quercus turbinella*) is tabulated.

190. CABLE, DWIGHT R. 1976. Twenty years of changes in grass production following mesquite control and reseeding. J. Range Manage. 29:286-289

In southern Arizona, mesquite (*Prosopis juliflora*) was controlled with 2,4,5-T. Herbage production with and without control is given in graphic form.

191. CABLE, DWIGHT R., and S. CLARK MARTIN. 1964. Forage production and stocking rates on southern Arizona ranges can be improved. U.S. Dep. Agric. For. Serv., Res. Note RM-30, 11 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Basal area and herbage production of annual and perennial grass under dead or alive velvet mesquite (*Prosopis juliflora*) on the Santa Rita Experimental Range are tabulated.

192. CABLE, DWIGHT R., and S. CLARK MARTIN. 1975. Vegetation responses to grazing, rainfall, site condition, and mesquite control on semidesert range. U.S. Dep. Agric. For. Serv., Res. Pap. RM-149, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Graphically illustrated is yearly grass production of sprayed (diesel oil) and unsprayed velvet mesquite (*Prosopis juliflora*) pastures along the Santa Rita Mountains, Ariz.

193. CABLE, DWIGHT R., and FRED H. TSCHIRLEY. 1961. Responses of native and introduced grasses following aerial spraying of velvet mesquite in southern Arizona. J. Range Manage. 14:155-159.

Tables describing grass production under sprayed (2,4,5-T) and unsprayed stands of velvet mesquite (*Prosopis juliflora*) are presented for the Santa Rita Experimental Range.

194. CLARY, WARREN P. 1969. Increased sampling precision for some herbage variables through knowledge of the timber overstory. J. Range Manage. 22:200-201.

Relationships of herbage production, perennial grass production, and forage consumed to percent ponderosa pine (*Pinus ponderosa*) crown cover in a study in Arizona are logarithmic.

195. CLARY, WARREN P. 1970. The relationship of herbage production on Springerville soils to Utah juniper overstory and precipitation. p. 69. *In* Abstr. of Pap., 23rd Annu. Meet., Am. Soc. Range Manage., Denver, Colo.

Herbage and perennial grass yields associated with intact Utah juniper overstory and overstory removed by cabling are described for a study area in north-central Arizona.

196. CLARY, WARREN P. 1971. Effects of Utah juniper removal on herbage yields from Springerville soils. J. Range Manage. 24:373-378.

Relationships between total understory (linear) and perennial grasses (curvilinear), and crown cover of Utah juniper (*Juniperus osteosperma*) and pinyon (*Pinus edulis*) overstory are graphically illustrated for a study area in north-central Arizona. Also, herbage yields with and without mechanical removal of overstory (table), and perennial grass production trends through time (graph) are presented.

197. CLARY, WARREN P. 1974. Pinyon-juniper control: does it pay? Annu. Ariz. Watershed Symp Proc. 18:26-29.

Results from Arizona studies are presented graphically showing relationships between herbage, trees, rainfall, and soils. Primary tree species are Utah juniper (*Juniperus osteosperma*) and alligator juniper (*J. deppeana*).

198. CLARY, WARREN P. 1974. Response of herbaceous vegetation to felling of alligator juniper. J. Range Manage. 27:387-389.

Herbage production with and without *Juniperus deppeana* overstories is shown by graph and table for central Arizona.

199. CLARY, WARREN P. 1975. Multiple use effects of manipulating pinyon-juniper. p. 459–477. *In* Watershed Manage. Symp., Am. Soc. Civil Eng., Irrig. and Drain. Div. [Logan, Utah, Aug. 11–13].
Relationships between herbage production, tree basal area, precipitation, and soils are presented graphically. Dominant overstory species in Arizona are *Juniperus osteosperma* and *J. deppeana*.

200. CLARY, WARREN P. 1975. Range management and its ecological basis in the ponderosa pine type of Arizona: the status of our knowledge. U.S. Dep. Agric. For. Serv., Res. Pap. RM-158, 35 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
The effect of varying densities of ponderosa pine (*Pinus ponderosa*) upon the amount of herbage produced on the Wild Bill Range and Beaver Creek watershed is graphically illustrated.

201. CLARY, WARREN P. 1978. Arizona fescue mountain rangelands. p. 205–207. *In* Proc. First Int. Rangeland Cong. Denver, Colo.
Relationship of herbage production to tree basal area is presented graphically for *Pinus ponderosa* overstories. These forested ranges are in Arizona, Colorado, and New Mexico.

202. CLARY, WARREN P. 1978. Producer-consumer biomass in Arizona ponderosa pine. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. RM-56, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
An equation describes the relationship between herbage production and *Pinus ponderosa* basal area for the Coconino Plateau of Arizona.

203. CLARY, WARREN P., MALCHUS B. BAKER, JR., PAUL F. O'CONNELL, and others. 1974. Effects of pinyon-juniper removal on natural resource products and uses in Arizona. U.S. Dep. Agric. For. Serv., Res. Pap. RM-128, 28 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Tabular data, graphics, and equations are used to show the relation of herbage production to Utah juniper (*Juniperus osteosperma*) and alligator juniper (*J. deppeana*) on the Beaver Creek watershed.

204. CLARY, WARREN P., and PETER F. FFOLLIOTT. 1966. Differences in herbage-timber relationships between thinned and unthinned ponderosa pine stands. U.S. Dep. Agric. For. Serv., Res. Note RM-74, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Herbage production under thinned and unthinned ponderosa pine (*Pinus ponderosa*) stands is compared by logarithmic equations for a study area in north-central Arizona.

205. CLARY, WARREN P., PETER F. FFOLLIOTT, and DONALD A. JAMESON. 1968. Relationship of different forest layers to herbage production. U.S. Dep. Agric. For. Serv., Res. Note RM-123, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
In north-central Arizona, logarithmic equations describe relationships between herbage production and individual layers and between herbage production and total depth of ponderosa pine (*Pinus ponderosa*) forest floor.

206. CLARY, WARREN P., PETER F. FFOLLIOTT, and ALMER D. ZANDER. 1966. Grouping sites by soil management areas and topography. U.S. Dep. Agric. For. Serv., Res. Note RM-60, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Relationships between herbage production and ponderosa pine (*Pinus ponderosa*) overstory density for different productivity strata are graphically illustrated for a study area in north-central Arizona.

207. CLARY, WARREN P., and HAROLD E. GRELEN. 1978. Comparison of beef gain potentials on cool semiarid and subtropical pine forest ranges. p. 600–602. *In* Proc. First Int. Rangeland Cong. Denver, Colo.
Relationships of forage value index and tree basal area are given for overstories of *Pinus ponderosa* in Arizona and *P. palustris-P. elliottii* in Louisiana.

208. CLARY, WARREN P., WILLIAM H. KRUSE, and FREDERIC R. LARSON. 1975. Cattle grazing and wood production with different basal areas of ponderosa pine. J. Range Manage. 28:434–437.
Tabular data describe understory production relative to *Pinus ponderosa* density levels in northern Arizona.

209. CLARY, WARREN P., and FREDERIC R. LARSON. 1971. Elk and deer use are related to food sources in Arizona ponderosa pine. U.S. Dep. Agric. For. Serv., Res. Note RM-202, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Herbage production associated with alligator juniper (*Juniperus deppeana*) and ponderosa pine (*Pinus ponderosa*) overstories is discussed.

210. CLARY, WARREN P., and DOUGLAS C. MORRISON. 1973. Large alligator junipers benefit early spring forage. J. Range Manage. 26:70–71.
In Arizona, a study was made of the effect of mature *Juniperus deppeana* on early forage. Data are presented in tabular form.

211. COOPER, CHARLES F. 1960. Production of native and introduced grasses in the ponderosa pine region of Arizona. J. Range Manage. 13:214–215.
A linear equation describing a relationship between grass production and percent crown cover of ponderosa pine overstory is given for a study area on the San Carlos Indian Reservation in east-central Arizona.

212. DWYER, DON D., and REX D. PIEPER. 1967. Fire effects on blue grama-pinyon-juniper rangeland in New Mexico. J. Range Manage. 20:359–362.
Production of grasses and forbs is described (table) for burned and unburned pinyon-juniper woodlands in south-central New Mexico. Pinyon (*Pinus edulis*) and one-seed juniper (*Juniperus monosperma*) are dominant overstory species.

213. FFOLLIOTT, PETER F., and WARREN P. CLARY. 1974. Predicting herbage production from forest growth in Arizona ponderosa pine. Prog. Agric. Ariz. 26(3):3–5.
Equations and graphics describe relationships between herbage production and timber (*Pinus ponderosa*) production.

214. FFOLLIOTT, PETER F., and WARREN P. CLARY. 1975. Differences in herbage-timber relationships on sedimentary and igneous soils in Arizona ponderosa pine stands. Prog. Agric. Ariz. 27(3):6–7.
Several relationships between herbage production and *Pinus ponderosa* on the Coconino National Forest are illustrated graphically. Effect of soils, grazing, and tree reproduction are discussed.

215. FFOLLIOTT, PETER F., WARREN P. CLARY, and FRED R. LARSON. 1976. Fire scene 11 years after. Prog. Agric. Ariz. 28(1):12–13.

The effects of prescribed burning of ponderosa pine, located on the Coconino National Forest, were studied. Herbage production for several timber densities is discussed.

216. FFOLLIOTT, PETER F., WARREN P. CLARY, and FREDERIC R. LARSON. 1977. Effects of prescribed fire in an Arizona ponderosa pine forest. U.S. Dep. Agric. For. Serv., Res. Note RM-336, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Describes changes in herbage production 11 years after prescribed fire was used to thin two *Pinus ponderosa* stands.

217. FFOLLIOTT, PETER F., and DAVID B. THORUD. 1975. Water yield improvement by vegetation management: focus on Arizona. Univ. Ariz., School of Renew. Nat. Resour. 1,094 p. [Available from Natl. Tech. Inf. Serv. as PB 246 005/AS.]

Herbage production before and after various treatments (cabling, felling, thinning, herbicide, and fire) are illustrated (graphs and tables) for aspen (*Populus tremuloides*), ponderosa pine (*Pinus ponderosa*), pinyon-juniper (*Juniperus spp. and Pinus* spp.), and oak (*Quercus* spp.) overstories in several Arizona study areas.

218. FFOLLIOTT, PETER F., and DAVID THORUD. 1977. Water resources and multiple-use forestry in the Southwest. J. For. 75:469–472.

Forage production with presence and absence of the overstory is given for forested and chaparral zones in Arizona.

219. FFOLLIOTT, PETER F., and DAVID P. WORLEY. 1965. An inventory system for multiple use evaluations. U.S. Dep. Agric. For. Serv., Res. Pap. RM-17, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

A localized predicting equation describing herbage production as a function of ponderosa pine overstory density is logarithmic for a study area in north-central Arizona.

220. GAINES, EDWARD M., HARRY R. KALLANDER, and JOE A. WAGNER. 1958. Controlled burning in southwestern ponderosa pine: results from the Blue Mountain plots, Fort Apache Indian Reservation. J. For. 56:323–327.

Grass density before and after controlled burning of ponderosa pine overstory is described (tables) for a study area in eastern Arizona.

221. GLENDENING, G. E., C. P. PASE, and P. INGEBO. 1961. Preliminary hydrologic effects of wildfire in chaparral. Annu. Ariz. Watershed Symp. Proc. 5:12–15.

Recovery of shrubs, forbs, and grasses following burning of chaparral overstory, and under different cultural treatments (seeding, seeding and spraying with 2,4,5-T, control) is described (table) for a study area in central Arizona.

222. HIBBERT, ALDEN R. 1971. Increases in streamflow after converting to grass. Water Resour. Res. 7:71–80.

Shrub cover and herbaceous production preceding and following a wildfire in chaparral are graphically illustrated for an area in central Arizona. Shrub live oak (*Quercus turbinella*) and birchleaf mountain mahogany (*Cercocarpus betuloides*) are the dominant species in the overstory.

223. HIBBERT, ALDEN R., EDWIN A. DAVIS, and DAVID G. SCHOLL. 1974 Chaparral conversion potential in Arizona, part 1: water yield response and effects on other resources. U.S. Dep. Agric. For. Serv., Res. Pap. RM-126, 36 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

On the Three Bar Wildlife Area in Arizona, chaparral brush (*Quercus turbinella, Q. chrysolepis, Q. emoryi, Cercocarpus betuloides, C. montanus, Arctostaphylos pungens, A. pringlei, Garry wrightii, G. flavescens, Ceanothus greggii, Rhus ovata, R. trilobata, Rhamnus crocea*, and *Eriodictyon angustifolium*) burned by wildfire, was allowed to recover or was sprayed with herbicide (2,4-D, 2,4,5-T, and silvex). Herbage production on the two treatment areas for 6 consecutive years is given (graph).

224. HIBBERT, ALDEN R., and PAUL A. INGEBO. 1971. Chaparral treatment effects on streamflow. Annu. Ariz. Watershed Symp. Proc. 15:25–34.

Herbaceous production before and after conversion (burning, herbicide) of chaparral overstory is discussed for a study area in central Arizona.

225. HUNGERFORD, C. R. 1970. Response of Kaibab mule deer to management of summer range. J. Wildl. Manage. 34:852–862.

The proportion of ground covered with plants associated with different forest types changed by seeding, logging, and fire is described (graphs) for a study area in northern Arizona. Forest types include ponderosa pine (*Pinus ponderosa*) and mixed conifer-aspen (*Populus tremuloides*).

226. JAMESON, DONALD A. 1962. Effects of burning on a galleta-black grama range invaded by juniper. Ecology 43:760–763.

The production of grasses is given (table) for burned and unburned one-seed juniper (*Juniperus monosperma*) forest stands for a study area in north-central Arizona.

227. JAMESON, DONALD A. 1966. Competition in a blue grama-broom snakeweed-actinea community and responses to selective herbicides. J. Range Manage. 19:121–124.

A table of correlation coefficients is given to illustrate the association among plant yields, including perennial grasses, broom snakeweed (*Gutierrezia sarothrae*), and Cooper actinea (*Hymenoxis cooperi*), on a study area in north-central Arizona.

228. JAMESON, DONALD A. 1966. Pinyon-juniper litter reduces growth of blue grama. J. Range Manage. 19:214–217.

Pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) litter is reported to be the major overstory factor associated with the reduction of blue grama (*Bouteloua gracilis*) on a study area in north-central Arizona.

229. JAMESON, DONALD A. 1967. The relationship of tree overstory and herbaceous understory vegetation. J. Range Manage. 20:247–249.

The use of a 5-parameter transition sigmoid growth curve to express the relationship between herbaceous understory and tree overstory is described and illustrated with data from north-central Arizona. Overstories considered are pinyon (*Pinus edulis*), juniper (*Juniperus* spp.), and ponderosa pine (*P. ponderosa*).

230. JAMESON, DONALD A. 1970. Juniper root competition reduces basal area of blue grama. J. Range Manage. 23:217-218.

A table of blue grama (*Bouteloua gracilis*) basal area with and without one-seed juniper (*Juniperus monosperma*) root competition is presented for a study area in northern Arizona.

231. JAMESON, DONALD A. 1971. Optimum stand selection for juniper control on southwestern woodland ranges. J. Range Manage. 24:94-99.

Equations describe relationships between herbage production and pinyon-juniper (*Pinus edulis, P. monophylla*, and *Juniperus* spp.) overstory with different grass growth forms and soils. The equation model used is a 5-parameter transition sigmoid growth curve.

232. JAMESON, DONALD A., and J. D. DODD. 1969. Herbage production differs with soil on the pinyon-juniper type of Arizona. U.S. Dep. Agric. For. Serv., Res. Note RM-131, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Herbage production associated with different soil series and pinyon-juniper overstory densities is given in tabular form.

233. JOHNSEN, THOMAS N., JR. 1962. One-seed juniper invasion of northern Arizona grasslands. Ecol. Monogr. 32:187-207.

Distribution of herbaceous vegetation around individual one-seed juniper (*Juniperus monosperma*) trees is graphically illustrated and detailed in tables.

234. JORDAN, GILBERT L., and MICHAEL L. MAYNARD. 1970. The San Simon watershed: revegetation. Prog. Agric. Ariz. 22(3):4-7.

The production of Lehmann lovegrass (*Eragrostis lehmanniana*) associated with different seedbed preparations (root plowed, disked plowed, or chained) is presented (table) for creosotebush (*Larrea tridentata*), mesquite (*Prosopis juliflora*), and mixed creosotebush-mesquite communities in southeastern Arizona.

235. KINCAID, D. R., G. A. HOLT, P. D. DALTON, and J. S. TIXIER. 1959. The spread of Lehmann lovegrass as affected by mesquite and native perennial grasses. Ecology 40:738-742.

In Arizona, the effects of competition among Lehmann lovegrass (*Eragrostis lehmanniana*), perennial grasses, and velvet mesquite (*Prosopis juliflora*) overstory are graphically illustrated.

236. KRUSE, WILLIAM H. 1972. Effects of wildfire on elk and deer use of a ponderosa pine forest. U.S. Dep. Agric. For. Serv., Res. Note RM-226, 3 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Changes in production of grasses, forbs, and shrubs before and after burning of ponderosa pine (*Pinus ponderosa*) on the Wild Bill Study Area, Ariz., is given (table).

237. KRUSE, WILLIAM H., RUSSELL P. BALDA, MICHAEL J. SIMONO, and others. 1979. Community development in two adjacent pinyon-juniper eradication areas twenty-five years after treatment. J. Environ. Manage. 8:237-247.

Tabular data are given for herbage production in treated and untreated *Juniperus* stands in central Arizona.

238. KUNDAELI, JOHN N., and HUDSON G. REYNOLDS. 1972. Desert cottontail use of natural and modified pinyon-juniper woodland. J. Range Manage. 25:116-118.

Shrub density and herbage production are compared to overstory tree density. Data are from Ft. Bayard Experimental Forest, New Mex. Overstory is primarily *Pinus edulis* and *Juniperus* spp. Data are presented in table form.

239. LARSON, M. M. and GILBERT H. SCHUBERT. 1969. Root competition between ponderosa pine seedlings and grasses. U.S. Dep. Agric. For. Serv., Res. Pap. RM-54, 12 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Relationships between different perennial grass cover types and ponderosa pine (*Pinus ponderosa*) seedling growth are given (tables and graphs) for the Fort Valley Experimental Forest in north-central Arizona.

240. LOWE, PHILIP O., PETER F. FFOLLIOTT, JOHN H. DIETERICH, and DAVID R. PATTON. 1978. Determining potential wildlife benefits from wildfires in Arizona ponderosa pine forests. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. RM-52, 12 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Basal area of grasses and forbs on burned areas 1, 3, 7, and 20 years old and on a control area in *Pinus ponderosa* forests in north-central Arizona is graphically compared.

241. MARTIN, S. CLARK. 1963. Grow more grass! by controlling mesquite. Prog. Agric. Ariz. 15(4):15-16.

Relation of grass produced per inch of summer rainfall received at the Santa Rita Experimental Range in southern Arizona to the number of mesquite trees on the site is graphically illustrated.

242. MARTIN, S. CLARK. 1966. The Santa Rita Experimental Range. U.S. Dep. Agric. For. Serv., Res. Pap. RM-22, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

A graph describes the relationship between the proportion of full production of grasses and velvet mesquite (*Prosopis juliflora*) overstory density for study area in southern Arizona.

243. MARTIN, S. CLARK. 1968. Improving semidesert ranges in southern Arizona, U.S.A. by grazing management and shrub control. Ann. of Arid Zone 7:235-242.

Perennial grass production with and without chemical control (2,4,5-T) of velvet mesquite (*Prosopis juliflora*) overstory is presented (table) for the Santa Rita Experimental Range.

244. MARTIN, S. CLARK. 1970. Vegetation changes on semidesert range during 10 years of summer, winter, and year-long grazing by cattle. Eleventh Int. Grassl. Congr. Proc. 11:23-26.

Relationships between herbage production and density, and density of burroweed (*Haplopappus tenuisectus*) are given (table) for different grazing periods on the Santa Rita Experimental Range in southern Arizona.

245. MARTIN, S. CLARK, and DWIGHT R. CABLE. 1962. Grass production high 14 years after mesquite control. Ariz. Cattlelog 18(12):48-61.

Grass production with mesquite overstory thinned, cleared, and undisturbed is given (table) for sites at different elevations on the Santa Rita Experimental Range in southern Arizona.

246. MARTIN, S. CLARK, and DWIGHT R. CABLE. 1974. Managing semidesert grass-shrub ranges: vegetation responses to precipitation, grazing, soil texture, and mesquite control. U.S. Dep. Agric. Tech. Bull. 1480, 45 p. Washington, D.C.
Velvet mesquite (*Prosopis juliflora*) on the Santa Rita Experimental Range in Arizona were sprayed with diesel oil. Herbage production for treated and untreated pastures is given (table and graph).
247. MARTIN, S. CLARK, JOHN L. THAMES, and ERNEST B. FISH. 1974. Changes in cactus numbers and herbage production after chaining and mesquite control. Prog. Agric. Ariz. 26(6):3–6.
On the Santa Rita Experimental Range, Ariz., cacti (*Opuntia fulgida, O. spinosior, O. versicolor, O. engelmannii*, and *Ferocactus wislizenii*) were chained and mesquite (*Prosopis juliflora*) were treated with diesel oil. Herbage production and percent composition of perennial grasses on the treated and untreated areas are shown in tables.
248. McCULLOCH, CLAY Y. 1966. Cliffrose browse yield on bulldozed pinyon-juniper areas in northern Arizona. J. Range Manage. 19:373–374.
Production of cliffrose (*Cowania mexicana*) browse associated with bulldozed and unbulldozed stands of pinyon-juniper (*Pinus edulis-Juniperus* spp.) overstory is presented in tabular form.
249. McCULLOCH, CLAY Y. 1969. Some effects of wildfire on deer habitat in pinyon-juniper woodland. J. Wildl. Manage. 33:778–784.
Herbaceous forage available 13 to 15 years after a wildfire is given (table) for burned and unburned pinyon (*Pinus edulis*) and juniper (*Juniperus osteosperma*) woodland type on the Hualapai Indian Reservation in northern Arizona.
250. NEFF, DON J. 1974. Forage preferences of trained mule deer on the Beaver Creek watersheds. Ariz. Game and Fish Dep. Spec. Rep. 4, 61 p.
Forage production on treated (cabled, thinned, clearcut, strip cut, or sprayed with herbicide) and untreated ponderosa pine (*Pinus ponderosa*) and juniper (*Juniperus deppeana* and *J. osteosperma*) in Arizona is tabulated.
251. O'CONNELL, PAUL F., and HARRY E. BROWN. 1972. Use of production functions to evaluate multiple use treatments on forested watersheds. Water Resour. Res. 8:1188–1198.
Illustrated (tables and graphs) are the changes in herbage production following clearcut and strip cut ponderosa pine (*Pinus ponderosa*), alligator juniper (*Juniperus deppeana*), and Utah juniper (*J. osteosperma*) on the Beaver Creek watershed in Arizona.
252. O'ROURKE, J. T., and P. R. OGDEN. 1969. Vegetative response following pinyon-juniper control in Arizona. J. Range Manage. 22:416–418.
A table describing perennial grass production with and without (mechanically removed) pinyon (*Pinus edulis*) and juniper (*Juniperus monosperma* and *J. osteosperma*) is presented.
253. O'ROURKE, J. T., and P. R. OGDEN. 1970. Pinyon-juniper control: where? why? Prog. Agric. Ariz. 22(1):12–15.
Total perennial grass and blue grama (*Bouteloua gracilis*) production on mechanically controlled and uncontrolled pinyon-juniper sites in east-central Arizona is graphically illustrated. Overstory is dominated by one-seed (*Juniperus monosperma*) and Utah juniper (*J. osteosperma*) and pinyon (*Pinus edulis*).
254. PARKER, KENNETH W., and S. CLARK MARTIN. 1952. The mesquite problem on southern Arizona ranges. U.S. Dep. Agric. Circ. 908, 70 p. Washington, D.C.
Graphs and tables describe the relations of grass yields to overstory of velvet mesquite (*Prosopis juliflora*) and burroweed (*Aplopappus tenuisectus*).
255. PASE, C. P., P. A. INGEBO, E. A. DAVIS, and C. Y. McCULLOCH. 1967. Improving water yield and game habitat by chemical control of chaparral. Int. Union For. Res. Organ. 14th Congr., Munich, Proc. 1:463–486.
Three-dimensional graphs depict herbage production following wildfire and herbicidal treatment (2,4,5-T) to *Cercocarpus betuloides* and *Quercus emoryi* on the Three Bar Watersheds, Ariz.
256. PASE, CHARLES P. 1970. Chaparral modification improves range forage and water yield in Arizona. p. 16. *In* 23d Annu. Meet., Am. Soc. Range Manage., Denver, Colo.
Herbage production with and without chemical control (2,4,5-T, fenuron, picloram, others) of chaparral stands is described.
257. PASE, CHARLES P. 1971. Effect of a February burn on Lehman lovegrass. J. Range Manage. 24:454–456.
Herbage production following root plowing and before and after burning shrub live oak (*Quercus turbinella*) is given (table) for a study area in central Arizona.
258. PASE, CHARLES P., and A. W. LINDENMUTH. 1971. Effects of prescribed fire on vegetation in oak-mountain mahogany chaparral. J. For. 69:800–805.
Herbaceous and shrub cover before and after prescribed fire in chaparral is given (tables and graph) for a study site on the Sierra Ancha Experimental Forest in central Arizona. Shrub live oak (*Quercus turbinella*) and true mountain mahogany (*Cercocarpus montanus*) dominate the overstory vegetation.
259. PASE, CHARLES P., and FLOYD W. POND. 1964. Vegetation changes following the Mingus Mountain burn. U.S. Dep. Agric. For. Serv., Res. Note RM-18, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Comparative yields of grass, forbs, and shrubs following a wildfire are presented (tables) for an area in central Arizona. The overstory is dominated by shrub live oak (*Quercus turbinella*) and skunkbush sumac (*Rhus trilobata*).
260. PATTEN, DUNCAN T. 1978. Productivity and production efficiency of an upper Sonoran desert ephemeral community. Am. J. Bot. 65:891–895.
In central Arizona, higher production efficiency for winter annuals existed under *Ceridium microphyllum* crowns than in the interspaces. Data are presented in graphic and tabular forms.
261. PATTON, DAVID R. 1969. Deer and elk use of a ponderosa pine forest in Arizona before and after timber harvest. U.S. Dep. Agric. For. Serv., Res. Note RM-139, 7 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Herbage production and the number of browse plants before and after logging of ponderosa pine overstory are described.

262. PATTON, DAVID R. 1974. Patch cutting increases deer and elk use of a pine forest in Arizona. J. For. 72:764-766.
Herbage production before and after clearcutting small patches of ponderosa pine (*Pinus ponderosa*), Gambel oak (*Quercus gambellii*), Douglas-fir (*Pseudotsuga menziesii*), true firs (*Abies spp.), southwestern white pine (P. strobiformis*), and quaking aspen (*Populus tremuloides*) are given in tabular form. Herbage yields are graphically related to ponderosa pine crown cover.

263. PATTON, DAVID R. 1976. Timber harvesting increases deer and elk use of a mixed conifer forest. U.S. Dep. Agric. For. Serv., Res. Note RM-329, 3 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Grass and forb production 3 years before and 2 years following a timber harvest of quaking aspen (*Populus tremuloides*) on the Apache National Forest in east-central Arizona is given (table).

264. PATTON, DAVID R., and B. IRA JUDD. 1970. The value of wet meadows as wildlife habitat in the Southwest. J. Range Manage. 23:272-275.
Herbage production associated with wet meadow, moist transition, and dry forest sites is presented (table) for a study area in east-central Arizona. The density and frequency of grasses and forbs are given (table) for the different vegetation sites.

265. PEARSON, H. A., J. R. DAVIS, and G. H. SCHUBERT. 1972. Effects of wildfire on timber and forage production in Arizona. J. Range Manage. 25:250-253.
Herbage quality and quantity are compared (tables) for burned and unburned ponderosa pine (*Pinus ponderosa*) overstory situations on the Wild Bill Range.

266. PEARSON, HENRY A. 1964. Studies of forage digestibility under ponderosa pine stands. Proc. Soc. Am. For. 1964:71-73.
A logarithmic equation describing herbage production as a function of ponderosa pine overstory density is given for experimental range units in north-central Arizona.

267. PEARSON, HENRY A. 1967. Phenology of Arizona fescue and mountain muhly in the northern Arizona ponderosa pine type. U.S. Dep. Agric. For. Serv., Res. Note RM-89, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Growth rate of Arizona fescue (*Festuca arizonica*) leaves as related to percent ponderosa pine canopy cover is presented in tabular form.

268. PEARSON, HENRY A., and DONALD A. JAMESON. 1967. Relationship between timber and cattle production on ponderosa pine range: the Wild Bill Range. 10 p. U.S. Dep. Agric. For. Serv., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
A relationship between herbage production and ponderosa pine overstory density is graphically illustrated for a study area in north-central Arizona.

269. PIEPER, REX D. 1968. Comparison of vegetation on grazed and ungrazed pinyon-juniper grassland sites in south-central New Mexico. J. Range Manage. 21:51-53.
Tables showing total herbage production and percent composition by species for both protected and grazed areas at Fort Stanton are given.

270. PIEPER, REX D. 1971. Blue grama vegetation responds inconsistently to cholla cactus control. J. Range Manage. 24:52-54.
A table describes herbage production on grubbed and ungrubbed cholla (*Opuntia imbricata*) sample plots in the Sacramento Mountains of New Mexico.

271. PIEPER, REX D. 1977. The southwestern pinyon-juniper ecosystem. *In* Ecology, uses, and management of pinyon-juniper woodlands: proceedings of the workshop. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. RM-39, 48 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Relationship of herbage to *Pinus-Juniperus* canopy cover is presented graphically.

272. POND, FLOYD W. 1961. Basal area and production of weeping lovegrass under varying amounts of shrub live oak crown cover. J. Range Manage. 14:335-337.
The basal area and production of weeping lovegrass (*Eragrostis curvula*) and the reduction of shrub live oak (*Quercus turbinella*) after burning are graphically illustrated. Also, a linear predicting equation relating grass production to reduction of overstory canopy is given.

273. POND, FLOYD W. 1961. Mechanical control of Arizona chaparral and some results from brush clearing. Annu. Ariz. Watershed Symp. Proc. 5:39-41.
Graphs describe relationship between basal area and production of weeping lovegrass (*Eragrostis curvula*) and reduction of shrub live oak (*Quercus turbinella*) canopy.

274. POND, FLOYD W. 1962. Shrub live oak limits production of weeping lovegrass. Ariz. Cattlelog 18(12):60-61.
Relationship between production of weeping lovegrass and reduction of shrub live oak canopy after burning is graphically illustrated for a study area in central Arizona.

275. POND, FLOYD W. 1964. Response of grasses, forbs, and halfshrubs to chemical control of chaparral in central Arizona. J. Range Manage. 17:200-203.
Herbage yields before and after spraying (2,4-D, 2,4,5-T) shrub live oak (*Quercus turbinella*) overstory are presented (graphs) for the Sierra Ancha Experimental Forest.

276. POND, FLOYD W. 1968. Changes in grass production on ungrazed converted chaparral. U.S. Dep. Agric. For. Serv., Res. Note RM-98, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Production and basal area of weeping lovegrass (*Eragrostis curvula*) related to control (2,4-D, 2,4,5-T) of shrub live oak (*Quercus turbinella*) overstory are described in graphic form for a study area in eastern Arizona.

277. POND, FLOYD W. 1969. Grazing values on undisturbed chaparral versus areas converted to grass: the Tonto Springs range. 14 p. U.S. Dep. Agric. For. Serv., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Production of perennial grasses before and after root plowing of chaparral overstory is discussed for a study area in central Arizona.

278. POND, FLOYD W., and DWIGHT R. CABLE. 1962. Recovery of vegetation following wildfire on a chaparral area in Arizona. U.S. Dep. Agric. For. Serv., Res. Note RM-72, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Basal area of weeping lovegrass (*Eragrostis curvula*) as related to crown cover of shrub overstory inside and outside an exclosure is presented in a table. The overstory is mainly shrub live oak (*Quercus turbinella*).

279. REYNOLDS, H. G., and J. W. BOHNING. 1956. Effects of burning on a desert grass-shrub range in southern Arizona. Ecology 37:769–777.
Density and production of perennial grasses are described (tables and graphs) before and after burning overstory on the Santa Rita Experimental Range. The overstory included burroweed (*Aplopappus tenuisectus*), cholla (*Opuntia* spp.), and mesquite (*Prosopis* spp.).
280. REYNOLDS, H. G., and F. H. TSCHIRLEY. 1957. Mesquite control on southwestern rangeland. U.S. Dep. Agric., Leafl. 421, 8 p. Washington, D.C.
A relationship between forage production and mesquite abundance is graphically illustrated.
281. REYNOLDS, HUDSON G. 1959. Brush control in the Southwest. *In* Grasslands. p. 379–389. Am. Assoc. Advancement Sci., Publ. 53.
The relative proportions of perennial grass and mesquite (*Prosopis juliflora*) overstory are graphically illustrated for southern Arizona and New Mexico.
282. REYNOLDS, HUDSON G. 1962. Effect of logging on understory vegetation and deer use in a ponderosa pine forest of Arizona. U.S. Dep. Agric. For. Serv., Res. Note 80, 7 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Understory vegetation production on logged and unlogged areas of ponderosa pine is presented (table). A graph illustrates the relationship between herbage yields and coniferous forest (ponderosa pine and Douglas-fir) overstory.
283. REYNOLDS, HUDSON G. 1962. Some characteristics and uses of Arizona's major plant communities. J. Ariz. Acad. Sci. 2:62–71.
A literature review, including a description of relationships between herbage production and tree overstory, is presented for different vegetation types in Arizona.
284 REYNOLDS, HUDSON G. 1964. Elk and deer habitat use of a pinyon-juniper woodland in New Mexico. Trans. North. Am. Wildl. Nat. Resour. Conf. 29:438–444.
Relations among perennial grasses, forbs, shrubs, and overstory density are presented in tabular form. The main overstory trees include pinyon (*Pinus edulis*), alligator (*Juniperus deppeana*) and Utah (*J. osteosperma*) juniper, and wavyleaf oak (*Quercus undulata*).
285. REYNOLDS, HUDSON G. 1966. Slash cleanup in a ponderosa pine forest affects use by deer and cattle. U.S. Dep. Agric. For. Serv., Res. Note RM-64, 3 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Production of herbaceous vegetation on sample plots with slash cleared and slash undisturbed after logging ponderosa pine (*Pinus ponderosa*) overstory is presented (table) for a study area in northern Arizona.
286. REYNOLDS, HUDSON G. 1969. Aspen grove use by deer, elk, and cattle in a southwestern coniferous forest. U.S. Dep. Agric. For. Serv., Res. Note RM-138, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
A table describing understory production, including aspen (*Populus tremuloides*) sprouts, under aspen and under mixed conifer forest types is presented for north-central Arizona. Mixed conifer species include Douglas-fir (*Pseudotsuga menziesii*), subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and ponderosa pine (*Pinus ponderosa*). A graph illustrating understory production in thinned and unthinned aspen groves is also included.
287. REYNOLDS, HUDSON G. 1969. Improvement of deer habitat on southwestern forest lands. J. For. 67:803–805.
Relations of herbaceous understory to ponderosa pine (*Pinus ponderosa*) overstory densities of mature and immature tree age groups are presented (table) for a study area on the Kaibab Plateau in northern Arizona.
288. REYNOLDS, HUDSON G., WARREN P. CLARY, and PETER F. FFOLLIOTT. 1970. Gambel oak for southwestern wildlife. J. For. 68:545–547.
Understory herbage production in relation to *Quercus gambelii* overstory is described for northern Arizona.
289. REYNOLDS, HUDSON G., and S. CLARK MARTIN. 1968. Managing grass-shrub cattle range in the Southwest. U.S. Dep. Agric., Agric. Handb. 162 rev., 44 p. Washington, D.C.
The relation of proportion of full production of perennial grass and density of velvet mesquite (*Prosopis juliflora*) is described (graph) for the Santa Rita Experimental Range in southern Arizona. Also, a graph illustrating average herbage production on sprayed (2,4,5-T) and unsprayed mesquite-infected range at different points in time is presented.
290. SCHMUTZ, ERVIN M., and DAVID W. WHITHAM. 1962. Shrub control studies in the oak-chaparral of Arizona. J. Range Manage. 15:61–67.
Increase in grass yields as related to percent reduction by chemicals (2,4,5-T and Silvex) in ground cover of shrub live oak (*Quercus turbinella*) overstory is illustrated (graphs) for a study area in central Arizona.
291. SCHUBERT, GILBERT H. 1974. Silviculture of southwestern ponderosa pine: the status of our knowledge. U.S. Dep. Agric. For. Serv., Res. Pap. RM-123, 71 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
The relationships between herbage production and tree density, basal area, and canopy closure of ponderosa pine (*Pinus ponderosa*) in the Southwest are illustrated (graphs).

292. SHORT, HENRY L., WAIN EVANS, and ERWIN L. BOEKER. 1977. The use of natural and modified pinyon pine-juniper woodlands by deer and elk. J. Wildl. Manage. 41:543–559.

Modification of *Pinus edulis-Juniperus* spp. woodlands at Fort Bayard, N. Mex., was investigated. Relationships obtained display total herbage, grasses, and forbs as a function of the density of tree overstory. Additional relationships include shrubs versus trees, and herbage versus shrubs.

293. SPRINGFIELD, H. W. 1976. Characteristics and management of southwestern pinyon-juniper ranges: the status of our knowledge. U.S. Dep. Agric. For. Serv., Res. Pap. RM-160, 32 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Graphically illustrated are: the relationship between understory species and canopy intercept of pinyon-juniper (*Pinus* spp. and *Juniperus* spp.); and changes in plant cover and herbage yields 13 years after chemical (2,4-D; 2,4,5-T; and PBA) and mechanical (burning, chaining, pushing, and hand grubbing) control of pinyon-juniper woodlands on National Forest lands in Arizona and New Mexico.

294. THATCHER, ALBERT P., and VIRGIL L. HART. Spy Mesa yields better understanding of pinyon-juniper in range ecosystem. J. Range Manage. 27:354–357.

The interrelationships of soil, grasses, and overstories (*Pinus edulis* and *Juniperus osteosperma*) in Arizona are discussed.

295. TIEDEMANN, ARTHUR R., and JAMES O. KLEMMEDSON. 1971. Effect of mesquite (*Prosopis juliflora*) trees on vegetation and soils in the desert grassland. p. 15–16. *In* 24th Annu. Meet., Am. Soc. Range Manage., Reno.

Abundance of perennial grasses under canopies of mesquite overstory is described for a study area in southern Arizona.

296. TIEDEMANN, ARTHUR R., and JAMES O. KLEMMEDSON. 1977. Effect of mesquite trees on vegetation and soils in the desert grassland. J. Range Manage. 30:361–367.

At the Santa Rita Experimental Range in southern Arizona, *Prosopis juliflora* was studied in relation to an understory of herbage and shrubs. Effects on understory biomass and cover are reported.

297. TIEDEMANN, ARTHUR R., and ERVIN M. SCHMUTZ. 1966. Shrub control and reseeding effects on the oak chaparral of Arizona. J. Range Manage. 19:191–195.

Graphs illustrate the relationship between grass production and oak chaparral (*Quercus turbinella*) crown cover as modified by burning and an herbicide (Silvex).

298. URNESS, PHILIP J. 1974. Deer use changes after root plowing in Arizona chaparral. U.S. Dep. Agric. For. Serv., Res. Note RM-255, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

On the Tonto Springs Range, Ariz., shrub live oak (*Quercus turbinella*) and other chaparral species were root plowed and sprayed with fenuron. Forb and grass production on treated and untreated plots are shown graphically.

299. WELSH, RICHARD G., and RELDON F. BECK. 1976. Some ecological relationships between creosotebush and bush muhly. J. Range Manage. 29:472–475.

Variation in several characteristics of creosotebush (*Larrea tridentata*) is given (tables) with and without bush muhly growing within the creosotebush canopy. Study was conducted near Las Cruces, N. Mex.

300. WHITTAKER, R. H., and W. A. NIERING. 1975. Vegetation of the Santa Catalina mountains, Arizona. V. Biomass, production, and diversity along the elevation gradient. Ecology 56:771–790.

Biomass and net primary productivity are given for the herbaceous, shrub, and tree layers for a variety of samples from fir (*Abies* spp.) forests to creosotebush (*Larrea divaricata*) deserts. The study was conducted in southern Arizona.

301. WRIGHT, HENRY A. 1978. The effect of fire on vegetation in ponderosa pine forests: a state-of-the-art review. Texas Tech University, Lubbock, Range and Wildl. Inf. Ser. 2, Coll. Agric. Sci. Publ. T-9-199, 21 p.

Presents data summaries from major *Pinus ponderosa* regions.

## Eastern

302. AHLGREN, CLIFFORD E. 1960. Some effects of fire on reproduction and growth of vegetation in northeastern Minnesota. Ecology 41:431–445.

Plant frequencies of understory vegetation are presented (tables) for burned and unburned study sites in the coniferous forests of the Lake States.

303. AHLGREN, H. L., M. L. WALL, K. J. MUCKENDRIM, and J. M. SURD. 1946. Yields of forage from woodland pastures on sloping land in southern Wisconsin. J. For. 44:709–711.

Forage yields are presented (tables) for woodland, natural openings, and renovated openings.

304. ALBAN, DAVID E. 1977. Influence on soil properties of prescribed burning under mature red pine. U.S. Dep. Agric. For. Serv., Res. Pap. NC-139, 8 p. North Cent. For. Exp. Stn., St. Paul, Minn.

In Minnesota, stands of *Pinus resinosa* were burned in the spring and summer annually, biennially, and periodically to control beaked hazel (*Corylus cornuta*). Average number of stems per acre of beaked hazel on treated and untreated plots is shown in tabulated form.

305. ANDERSON, R. C., O. L. LOUCKS, and A. M. SWAIN. 1969. Herbaceous response to canopy cover, light intensity, and throughfall precipitation in coniferous forests. Ecology 50:255–263.

A linear equation defines relationship between herbaceous understory cover and percent of overstory canopy cover for two stands of red pine and white pine in northern Wisconsin. Also, the relationship is graphically illustrated.

306. BASKETT, THOMAS S., ROBERT L. DUNKESON, and S. CLARK MARTIN. 1957. Responses of forage to timber stand improvement in the Missouri Ozarks. J. Wildl. Manage. 21:121–126.

The production of browse, grass, and forbs following release through girdling a post oak-blackjack oak forest in Missouri is presented with tables and graphs. The dominant overstory consisted of post oak (*Quercus stellata*), blackjack oak (*Q. marilandica*), black oak (*Q. velutina*), and hickory (*Carya texana*).

307. BASKETT, THOMAS S., ROBERT DUNKESON, and S. CLARK MARTIN. 1958. Ten-year timber cutting cycle provides a continuing supply of forage. U.S. Dep. Agric. For. Serv., Cent. States For. Exp. Stn., Stn. Note 125, 2 p. Columbus, Ohio.

The changes in frequencies of forbs, grasses, and browse following release (cutting) in a white oak stand are compared with understory vegetation in uncut white oak for a study area in the Missouri Ozarks.

308. BJUGSTAD, ARDELL J., DEAN A. MURPHY, and HEWLETTE S. CRAWFORD. 1968. Poor returns from Ozark woodland grazing. U.S. Dep. Agric. For. Serv., Res. Note NC-60, 2 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Production of forage, including grasses and forbs, is given (table) for commercial forest types in the Missouri Ozarks. Forest types include black-scarlet oak, pine, pine-oak, mixed hardwood, and white oak.

309. BROWN, JAMES H., and CALVIN B. DUNWOODY. 1961. Aerial spraying of 2,4,5-T for releasing conifers in Rhode Island. J. For. 59:882-884.

Tables describe the effect of different applications of 2,4,5-T on hardwood understory. The spraying objective was to release high-valued white pine (*Pinus strobus*).

310. BROWN, JAMES H., JR. 1960. The role of fire in altering the species composition of forests in Rhode Island. Ecology 41:310-316.

The relative density of understory vegetation is described (tables) for burned and unburned upland sites in the woodlands of Rhode Island. Scarlet (*Quercus coccinea*), white (*Q. alba*), and black oak (*Q. velutina*) are the major overstory occupants.

311. BROWN, JAMES M. 1973. Effect of overstory removal on production of shrubs and sedge in a northern Minnesota bog. J. Minn. Acad. Sci. 38:96-97.

Frequency and cover of understory is presented in graphic and tabular form for forested and clearcut *Picea mariana* stands.

312. BUCKMAN, ROBERT E. 1964. Effects of prescribed burning on hazel in Minnesota. Ecology 45:626-629.

The density of hazel (*Corylus* spp.) associated with burning red pine (*Pinus resinosa*) overstory is presented in tabular form.

313. BUELL, MURRAY F., and JOHN E. CANTLON. 1953. Effects of prescribed burning on ground cover in the New Jersey pine region. Ecology 34:520-528.

The density of herbaceous vegetation with and without burning of pine-oak forest overstories is graphically illustrated.

314. COOK, DAVID B. 1939. Thinning for browse. J. Wildl. Manage. 3:201-202.

The effect of thinning second-growth northern hardwoods upon browse production is described for a study tract in New York.

315. CRAWFORD, H. S., and A. J. BJUGSTAD. 1967. Establishing grass range in the southwest Missouri Ozarks. U.S. Dep. Agric. For. Serv., Res. Note NC-22, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.

A comparison between grass production on study sites seeded and unseeded after spraying (2,4,5-T), burning, and fertilizing in hardwood stands is graphically illustrated. Overstory trees are primarily post and blackjack oak.

316. CRAWFORD, HEWLETTE S. 1976. Relationships between forest cutting and understory vegetation; an overview of eastern hardwood stands. U.S. Dep. Agric. For. Serv., Res. Pap. NE-349, 9 p. Northeast. For. Exp. Stn., Upper Darby, Pa.

Herbage production following varying intensities of cutting Ozark oak-hickory and Appalachian oak-pine stands is shown (tables).

317. CRAWFORD, HEWLETTE S., JR. 1971. Wildlife habitat changes after intermediate cutting for even-aged management. J. Wildl. Manage. 35:275-286.

Multiple regression analyses describe the relationships between growth of understory vegetation and forest overstory density and site quality for a study area in south-central Missouri. Also, growth of understory vegetation is described (tables) for different forest overstory levels and site quality classes. The overstory is dominated by black (*Quercus velutina*), white (*Q. alba*), scarlet (*Q. coccinea*), and northern red (*Q. rubra*) oak.

318. CRAWFORD, HEWLETTE S., JR., and WAYNE M. HARRISON. 1971. Wildlife food on three Ozark hardwood sites after regeneration cutting. J. Wildl. Manage. 35:533-537.

Understory vegetation production is described (table) by site class and growing seasons after regeneration (clear) cutting black (*Quercus velutina*) and scarlet oak (*Q. coccinea*) on the Ozark Plateau of south-central Missouri.

319. CROW, T. R. 1978. Biomass and production in three contiguous forests in northern Wisconsin. Ecology 59:265-273.

Biomass tabular data are given for tree, shrub, and ground vegetation from three forest communities containing *Populus*, *Betula*, and *Acer* overstories.

320. DALKE, PAUL D. 1941. The use and availability of the more common winter browse plants in the Missouri Ozarks. Trans. North. Am. Wildl. Conf. 6:155-160.

The yield of browse species in post oak-blackjack oak, black oak-hickory, and ravine forest cover types is given in tabulated form.

321. DEITSCHMAN, GLENN H. 1956. Growth of underplanted hardwoods in black locust and shortleaf pine plantations. U.S. Dep. Agric. For. Serv., Central States For. Exp. Stn., Stn. Note 94, 2 p. Columbus, Ohio.

Growth (height) of planted hardwood understory is presented (table) for black locust and shortleaf pine overstories for plantations in southern Illinois.

322. DILLER, OLIVER, D. 1937. The forage cover in heavily grazed farm woods of northern Indiana. J. Am. Soc. Agron. 29:924-933.

Frequency and percent cover of understory vegetation under oak-hickory and beech-maple overstories are graphically illustrated.

323. EHRENREICH, JOHN H. 1959. Releasing understory pine increased herbage production. U.S. Dep. Agric. For. Serv., Cent. States For. Exp. Stn., Stn. Note 139, 2 p. Columbus, Ohio.

Changes in forage production on sprayed (2,4,5-T) and unsprayed study areas in Missouri are graphically illustrated. The spraying objective was to release underplanted pine in mixed pine-oak woodlands.

324. EHRENREICH, JOHN H. 1960. Useable forage under pine stands. U.S. Dep. Agric. For. Serv., Cent. States For. Exp. Stn., Stn. Note 142, 2 p. Columbus, Ohio.

Herbage production in relation to thinning intensity and time since thinning is described (graph) for a natural shortleaf pine stand on the Sinkin Experimental Forest in southern Missouri.

325. EHRENREICH, JOHN H., and ROBERT F. BUTTERY. 1960. Increasing forage on Ozark wooded range. U.S. Dep. Agric. For. Serv., Cent. States For. Exp. Stn., Stn. Tech. Pap. 177, 10 p. Columbus, Ohio.

Forage production associated with the elimination of woody overstory, artificial seeding, and fertilization is described (graph) for study sites in the Missouri Ozarks. Overstory includes *Quercus velutina* (black oak), *Q. marilandica* (blackjack oak), *Q. coccinea* (scarlet oak), and *Q. stellata* (post oak).

326. EHRENREICH, JOHN H., ROBERT F. BUTTERY, and CHARLES W. GEHRKE. 1960. How good is Ozark forage? Univ. Missouri, Columbia, Agric. Exp. Stn. Bull. 759, 7 p.

Forage produced on forest range is discussed.

327. EHRENREICH, JOHN H., and JOHN S. CROSBY. 1960. Forage production on sprayed and burned areas in the Missouri Ozarks. J. Range Manage. 13:68–70.

Tables of herbage yields on sprayed (2,4,5-T), burned, and untreated (control) areas of blackjack (*Quercus marilandica*) and post oak (*Q. stellata*).

328. EHRENREICH, JOHN H., and JOHN S. CROSBY. 1960. Herbage production is related to hardwood crown cover. J. For. 58:564–565.

Relationship between herbage production and hardwood overstory crown cover is graphically illustrated for the Missouri Ozarks. Overstory is dominated by blackjack (*Quercus marilandica*) and post oak (*Q. stellata*).

329. EHRENREICH, JOHN H., and DEAN A MURPHY. 1962. A method of evaluating habitat for forest wildlife. Trans. North. Am. Wildl. Nat. Resour. Conf. 27:376–384.

Grass, forb, and browse production in different stand size and stocking classes, and in several forest types, is given (tables) for the Missouri Ozarks.

330. EHRENREICH, JOHN H., and ROBERT A. RALSTON. 1963. Forage and timber production alternatives on shallow soils in the Ozarks. Proc. Soc. Am. For. 1963:80–83.

Forage production associated with clearing of hardwood (oak-hickory) overstory is discussed.

331. ERDMANN, GAYNE G. 1967. Chemical weed control increases survival and growth in hardwood plantings. U.S. Dep. Agric. For. Serv., Res. Note NC–34, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.

A relationship between chemical removal (atrazine, simazine) of herbaceous ground cover and resulting survival and growth of hardwood tree species is described (table) for a study area in east-central Iowa. Tree species include black walnut (*Juglans nigra*), red oak (*Quercus rubra*), yellow poplar (*Liriodentron tulipifera*), and white ash (*Fraxinus americana*).

332. GRIGAL, D. F., and LEWIS F. OHMANN. 1975. Classification, description, and dynamics of upland plant communities within a Minnesota wilderness area. Ecol. Monogr. 45:389–407.

A table summarizing the percent cover of low shrubs, herbaceous plants, and ground cover plants for 13 upland plant community types within the Boundary Waters Canoe Area is given.

333. GYSEL, LESLIE W. 1957. Effects of silvicultural practices on wildlife food and cover in oak and aspen types of northern Michigan. J. For. 55:803–809.

The frequency and production of understory plants associated with different cultural practices designed to eliminate oak overstory to release pine and associated with different harvest cutting practices for aspen are described. Cultural treatments analyzed included girdling; basal spraying with a mixture of 2,4-D and 2,4,5-T; 2,4,5-T applied in frills; and aerial spraying with 2,4,5-T. Aspen cutting experiments were complete clearcut and commercial clearcut.

334. GYSEL, LESLIE W., and FOREST STEARNS. 1968. Deer browse production of oak stands in central lower Michigan. U.S. Dep. Agric. For. Serv., Res. Note NC–48, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Browse production is described (tables) in old growth (closed) and recently cut (open) oak stands. Overstory includes white (*Quercus alba*), northern red (*Q. rubra*), and northern pin oak (*Q. ellipsoidalis*), and red maple (*Acer rubrum*).

335. JORDAN, MARILYN J. 1975. Effects of zinc smelter emissions and fire on a chestnut oak woodland. Ecology 56:78–91.

Percent cover of shrubs and herbs on burned and unburned study sites (dominated by *Quercus prinus*) near Lehigh Water Gap in Pennsylvania is shown in tabulated form.

336. KENNEDY, PATRICK C., and LOUIS F. WILSON. 1971. Understory vegetation associated with Saratoga spittlebug damage in Michigan red pine plantations. Can. Entomol. 103:1421–1426.

Ground cover of understory is illustrated graphically and in tables in relation to spittlebug damage of *Pinus resinosa* overstory.

337. KNIERIM, PHILLIP G., KENNETH L. CARVELL, and JOHN D. GILL. 1971. Browse in thinned oak and cove hardwood stands. J. Wildl. Manage. 35:163–168.

Density of seedling-origin and sprout-origin browse associated with different thinning patterns and intensities is given (tables) for study plots on the West Virginia University Forest. The dominant species in the oak plots were *Quercus coccinea* (scarlet oak), *Q. rubra* (northern red oak), and *Q. alba* (white oak); the dominant species in the cove hardwood plots were yellow poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), and northern red oak.

338. KREFTING, L. W., and R. L. PHILLIPS. 1970. Improving deer habitat in upper Michigan by cutting mixed-conifer swamp. J. For. 68:701–704.

Available browse production associated with different cutting practices is given in tabular form. The major overstory trees are *Thuja occidentalis* (white cedar), *Picea mariana* (black) and *P. glauca* (white spruce), and *Abies balsamea* (balsam fir).

339. KREFTING, LAURITS W., and CLIFFORD E. AHLGREN. 1974. Small mammals and vegetation changes after fire in a mixed conifer-hardwood forest. Ecology 55:1391–1398.

Two burned areas and an unburned control site dominated by black spruce (*Picea mariana*), jack pine (*Pinus banksiana*), and paper birch (*Betula papyrifera*) on the Superior National Forest, Minn., were compared in terms of plant and animal species present. Changes in plant species composition (percent) following wildfire are shown (graphs and tables).

340. KREFTING, LAURITS W., and HENRY L. HANSEN. 1969. Increasing browse for deer by aerial applications of 2,4-D. J. Wildl. Manage. 33:784–790.
In the Tamarac National Wildlife Refuge in Minnesota, herbicide was applied to plots in each of four cover types: aspen (*Populus tremuloides*), jack pine (*Pinus banksiana*), oak (*Quercus* spp.), and upland brush. Browse production for treated and control plots is given in tabulated form.

341. LOOMIS, ROBERT M. 1977. Wildfire effects on an oak-hickory forest in southeast Missouri. U.S. Dep. Agric. For. Serv., Res. Note NC–219, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.
Herbaceous and woody understory was studied in burned and unburned *Quercus-Carya* forest stands. Data are given in tabulated and graphic forms.

342. LUTZ, H. J. 1932. Relation of forest site quality to number of plant individuals per unit area. J. For. 30:34–38.
Compares the number of herbaceous and shrubby individuals and the number of trees on good and poor sites for a study area in Connecticut.

343. MARQUIS, DAVID A. 1974. The impact of deer browsing on Allegheny hardwood regeneration. U.S. Dep. Agric. For. Serv., Res. Pap. NE–308, 8 p. Northeast. For. Exp. Stn., Upper Darby, Pa.
On the Allegheny Plateau (Pennsylvania and New York), deer exclosures were created on areas of hardwood stands (*Acer* spp., *Betula* spp., *Populus* spp., et al.) that had been clearcut 5 to 16 years earlier. Percent ground cover of rubus, ferns, and grasses on fenced and unfenced plots is shown in tabulated form.

344. MARTIN, S. CLARK, ROBERT L. DUNKESON, and THOMAS S. BASKETT. 1955. Timber harvests help offset forage decline in Missouri-managed forests. J. For. 53:513–516.
The frequency and composition of forage plants in openings and under *Quercus alba* (white oak) and *Q. velutina* (black oak) forest canopy are compared graphically and in tables.

345. MAXEY, WILLIAM R. 1976. Response of greenbrier to various silvicultural treatments under oak stands. Wildl. Soc. Bull. 4:186–188.
Number of greenbrier (*Smilax* spp.) stems per hectare are graphically compared to various silvicultural treatments applied to mixed oak (*Quercus* spp.) overstory on the West Virginia University Forest.

346. MURPHY, DEAN A., and HEWLETTE S. CRAWFORD. 1970. Wildlife foods and understory vegetation in Missouri's National Forests. Missouri Dep. Conserv., Tech. Bull. 4, 47 p.
A relationship between average understory yields and average overstory density is described for different forest types. Also, production of preferred wildlife foods as related to overstory density, and understory production in relation to logging and timber stand improvement work is presented in tabular form. Black and scarlet oak (*Quercus velutina* and *Q. coccinea*) forest type is the most abundant, with lesser acreage of white oak (*Q. alba*), post and blackjack oak (*Q. stellata* and *Q. marilandica*), and other forest types.

347. MURPHY, DEAN A., and JOHN H. EHRENREICH. 1956. Fruit-producing trees and shrubs in Missouri's Ozark forests. J. Wildl. Manage. 29:497–503.
The abundance of fruit-producing trees and shrubs as related to forest types and the abundance and fruiting of trees and shrubs as related to percent of overstory crown cover are presented in tabulated form.

348. MURPHY, DEAN A., and JOHN H. EHRENREICH. 1964. Effects of timber harvest and stand improvement on forage production. J. Wildl. Manage. 29:734–739.
Forage production following timber harvest or timber stand improvement of different forest types in Missouri Ozarks is given in tabulated form. Forest types considered were pine (*Pinus echinata*), oak-pine, black oak-scarlet oak, white oak, and red cedar.

349. NIERING, WILLIAM A., and RICHARD H. GOODWIN. 1974. Creation of relatively stable shrublands with herbicides: arresting "succession" on right-of-way and pastureland. Ecology 55:784–795.
Within the Connecticut Arboretum, *Quercus rubra, Q. alba*, and *Q. velutina* (red, white, and black oak) were sprayed with 2,4,5-T - fuel oil combination. Percent cover of vascular plants (trees, shrubs, vines, and herbs) before treatment and 2 decades following conversion is given (table).

350. OHMANN, LEWIS F., and DAVID F. GRIGAL. 1979. Early revegetation and nutrient dynamics following the 1971 Little Sioux forest fire in northeastern Minnesota. For. Sci. Monogr. 21, 80 p.
Plant communities primarily dominated by *Pinus banksiana* and by *Populus-Betula* were studied following wildfire. Changes through time by cover and biomass for both overstory and understory are presented in tabulated and graphic form.

351. OVINGTON, J. D., DALE HEITKAMP, and DONALD B. LAWRENCE. 1963. Plant biomass and productivity of prairie, savanna, oakwood, and maize field ecosystems in central Minnesota. Ecology 44:52–63.
Total production of understory and overstory is presented (tables) for the Cedar Creek Natural History Area. The overstory is dominated by bur (*Quercus microcarpa*) and northern red oak (*Q. rubra*).

352. PERALA, DONALD A. 1974. Repeated prescribed burning in aspen. U.S. Dep. Agric. For. Serv., Res. Note NC–171, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.
Regeneration and recovery of volume growth of shrubs after repeated burning of quaking aspen (*Populus tremuloides*) on the Chippewa National Forest, Minn., are given (table and graphs).

353. PETERS, ELROY J., and WILLIS G. VOGEL. 1963. Increasing forage production on Ozark ranges by spraying, seeding, and fertilizing. Agron. Abstr. 1963:121.
Herbage production following spraying (2,4,5-T), seeding (mixtures of perennial grasses), and fertilizing (8–24–8) on a forest range is discussed. Overstory species include *Quercus stellata* (post oak), *Q. marilandica* (blackjack oak), *Q. alba* (white oak), and *Q. velutina* (black oak).

354. PHILLIPS, JOHN J. 1963. Advance reproduction under mature oak stands of the New Jersey coastal plain. U.S. Dep. Agric. For. Serv., Res. Note NE–4, 5 p. Northeast For. Exp. Stn., Upper Darby, Pa.
The average density of woody understory vegetation under oak stands is given by sites, including wet, moist, and dry (table).

355. PRUETT, EMERSON W., and GORDON E. GATHERUM. 1962. Control of herbaceous vegetation in forest plantings. Iowa Acad. Sci. 68:153–161.
Relationships between control (chemical and mechanical) of herbaceous vegetation and survival and growth of planted tree species on a study area in east-central Iowa are discussed. Tree species include eastern white (*Pinus strobus*) and jack pine (*P. banksiana*), black walnut (*Juglans nigra*), and the eastern cottonwood (*Populus deltoides*).

356. REINERS, W. A. 1972. Structure and energetics of three Minnesota forests. Ecol. Monogr. 42:71-94.
Three topographic gradients representing three forest types: oak (*Quercus ellipsoidalis*), fen (dominant species: *Fraxinus nigra, Acer rubrum*, and *Ulmus americana*), and cedar swamp (*Thuja occidentalis*) on the Anoka Sand Plain were compared in terms of radiation, biomass, production, and detritus weight and energy values. Total biomass and annual aerial production for herbaceous and low shrub species are also given for the three gradients (table).

357. ROGERS, NELSON F., and K. A. BRINKMAN. 1965. Shortleaf pine in Missouri: understory hardwoods retard growth. U.S. Dep. Agric. For. Serv., Res. Pap. CS-15, 9 p. Cent. States For. Exp. Stn., Columbus, Ohio.
Relationship between control of hardwood understory and shortleaf pine (*Pinus echinata*) is presented in tabular form.

358. SHARP, WARM M. 1963. The effects of habitat manipulation and forest succession on ruffed grouse. J. Wildl. Manage 27:664-667.
Increases in understory vegetation following the cutting of openings in *Quercus* spp. (oak) communities on Pennsylvania State game lands are described.

359. SICCAMA, THOMAS G. 1974. Vegetation, soil, and climate on the Green Mountains of Vermont. Ecol. Monogr. 44:325-349.
Along an altitudinal gradient on the Green Mountains, there exist three forest types: deciduous (dominated by *Acer saccharum, Fagus grandifolia*, and *Betula alleghaniensis*), transitional (*Picea rubens* and *Abies balsamea*), and boreal (*Abies balsamea* and *Betula papyrifera*). Presence percentages of understory trees, shrubs, and herbs are shown (table and graph).

360. SMITH, RICHARD MERIWETHER. 1942. Some effects of black locusts and black walnuts on southeastern Ohio pastures. Soil Sci. 53:385-398.
Tabular values show a slight increase in herbage production and protein content under widely spaced black locust and black walnut trees, as compared to no trees.

361. TAYLOR, R. J., and R. W. PEARCY. 1976. Seasonal patterns of the $CO_2$ exchange characteristics of understory plants. Can. J. Bot. 54:1094-1103.
In a New York study, carbon dioxide exchange characteristics of understory plants were shown to vary according to the relation of their phenology to timing of overstory deciduous leaf development.

362. TIERSON, WILLIAM C., EARL F. PATRIC, and DONALD F. BEHREND. 1966. Influence of white-tailed deer on the logged northern hardwood forest. J. For. 64:801-805.
Average height and density of woody shrubs at different time periods following partial cutting of *Acer saccharum* (sugar maple), *Fagus grandifolia* (beech), and *Betula alleghaniensis* (yellow birch) overstory are graphically illustrated for deer exclosures in the central Adirondacks of New York.

363. VOGEL, WILLIS G., and ELROY J. PETERS. 1961. Spraying, seeding, and fertilizing increase forage on Ozark ranges. U.S. Dep. Agric. For. Serv., Cent. States For. Exp. Stn., Stn. Note 152, 2 p. Columbus, Ohio.
Herbage yields before and after spraying (2,4,5-T) post oak (*Quercus stellata*) overstory and yields associated with different seeding and fertilizing treatments are given.

364. WHITFORD, PHILIP C., and PHILIP B. WHITFORD. 1978. Effects of trees on ground cover in oil field succession. Am. Midl. Nat. 99:435-443.
The cover of herbaceous understory in relation to *Quercus ellipsoidalis* overstory was studied in central Wisconsin. Data are presented in tabular form.

365. WHITTAKER, R. H., and G. M. WOODWELL. 1969. Structure, production, and diversity of the oak-pine forest at Brookhaven, New York. J. Ecol. 57:155-174.
Tables describe the production of different plant life forms on a study site in New York. The overstory is dominated by *Quercus alba* (white oak) and *Q. coccinea* (scarlet oak).

366. ZAVITKOVSKI, J. 1976. Ground vegetation biomass, production, and efficiency of energy utilization in some northern Wisconsin forest ecosystems. Ecology 57:694-706.
Understory characteristics under forest overstories, including *Populus tremuloides, Betula papyrifera, Acer rubrum, Quercus rubra, Tilia americana*, and *Fraxinus americana* are presented in tabular form.

## Southern

367. BEASOM, SAMUEL L., and CHARLES J. SCIFRES. 1977. Population reactions of selected game species to aerial herbicide applications in south Texas. J. Range Manage. 30:138-142.
Honey mesquite (*Prosopis glandulosa*) was sprayed with 2,4,5-T and picloram. Herbage production, frequency, and density were described for sprayed and unsprayed areas.

368. BJERREGAARD, R. S., J. A. KEATON, K. E. McNEILL, and L. C. WARNER. 1968. Rangeland brush and weed control with tebuthiuron. *In* Proc. First Int. Rangeland Cong. p. 654-656. Denver, Colo.
Forage production with and without herbicide application for various woody overstories in Texas is evaluated (tables).

369. BLAIR, ROBERT M. 1960. Deer forage increased by thinnings in a Louisiana loblolly pine plantation. J. Wildl. Manage. 24:401-405.
Understory vegetation production, including grasses, forbs, and browse, under loblolly pine (*Pinus taeda*) stands following different intensities of thinning is given in tabular form.

370. BLAIR, ROBERT M. 1967. Deer forage in a loblolly pine plantation. J. Wildl. Manage. 31:432-437.
Multiple linear and logarithmic relations describing browse yields as functions of midstory hardwoods and loblolly pine (*Pinus taeda*) overstory density are given for a study area in central Louisiana. Also, tables of browse and herbage yields under loblolly pine stands thinned to different levels are presented.

371. BLAIR, ROBERT M. 1969. Timber stand density influences food and cover. *In* White-tailed deer in the Southern forest habitat, proc. symp. p. 74-76. U.S. Dep. Agric. For. Serv., South. For. Exp. Stn., New Orleans, La. [Published in cooperation with the Wildlife Society and Stephen F. Austin State University.]
A literature review, including a discussion of the production of grasses, forbs, and browse as related to overstory density, is presented for white-tailed deer habitat in the South.

372. BLAIR, ROBERT M. 1971. Forage production after hardwood control in a southern pine-hardwood stand. For. Sci. 17:279–284.

Herbage and browse yields before and after four intensities and two methods (girdling and the herbicide Ammate) of hardwood removal are given (table) for a study area in central Louisiana. Predominant overstory species include *Pinus taeda* (loblolly pine) and *P. echinata* (shortleaf pine) with *Quercus stellata* (post oak) comprising 75 percent of the hardwood stocking.

373. BLAIR, ROBERT M., and LOUIS E. BRUNETT. 1976. Phytosociological changes after timber harvest in a southern pine ecosystem. Ecology 57:18–32.

Following a selection timber harvest of *Pinus taeda, P. echinata, Quercus alba*, and *Q. falcata* on the Kisatchie National Forest, La., changes in the plant community were studied for 11 years. Net primary productivity in the herb and shrub strata is given (table and graph).

374. BLAIR, ROBERT M., and HANS G. ENGHARDT. 1976. Deer forage and overstory dynamics in a loblolly pine plantation. J. Range Manage. 29:104–108.

Linear and logarithmically transformed variables were used to analyze the relationship between herbage yields and pine and hardwood overstories. Some graphic relations are presented. Study was conducted on Alexander State Forest in central Louisiana on loblolly pine (*Pinus taeda*) plantations. Sweetgum (*Liquidambar styraciflua*) was the principal midstory component.

375. BLAIR, ROBERT M., and DONALD P. FEDUCCIA. 1977. Midstory hardwoods inhibit deer forage in loblolly pine plantations. J. Wildl. Manage. 41:677–684.

In central Louisiana, studies were made of a *Pinus taeda* overstory, a hardwood (mainly *Liquidambar styraciflua*) midstory, and a browse and herbaceous understory. Tables show relation between overstory and midstory, between midstory removal and understory responses, and between herbage and residual overstory.

376. BOVEY, R. W., R. E. MEYER, and H. L. MORTON. 1972. Herbage production following brush control with herbicides in Texas. J. Range Manage. 25:136–142.

Live oak (*Quercus virginiana*) whitebrush (*Aloysia lycioides*), yaupon (*Ilex vomitoria*) and other species were controlled by chemicals (picloram, bromacil, 2,4,5-T, dicamba, atrazine, and 2,4-D). Effects on herbage production are discussed (tables).

377. BOWER, DAVID R., and EDWIN R. FERGUSON. 1968. Understory removal improves shortleaf pine growth. J. For. 66:421–422.

In the Ouachita Mountains of Arkansas, complete and partial removal of hardwood understory increased growth of shortleaf pine (*Pinus echinata*) overstory. Linear prediction equations are presented to describe growth response.

378. BOX, THADIS W., JEFF POWELL, and D. LYNN DRAWE. 1967. Influence of fire on south Texas chaparral communities. Ecology 48:955–961.

The frequency of shrubs on burned and unburned study plots and the canopy reduction following burning of a chaparral community are presented in tabulated form.

379. BRATTON, SUSAN POWER. 1975. A comparison of the beta diversity functions of the overstory and herbaceous understory of a deciduous forest. Bull. Torrey Bot. Club 102:55–60.

In the Great Smoky Mountains National Park, Tenn., diversities of understory and overstory changed at different rates with changes in environmental conditions. Data are presented graphically for these *Fagus grandifolia*-dominated overstories.

380. BRENDER, ERNST V., W. HENRY McNAB, and SHELTON WILLIAMS. 1976. Fuel accumulations in Piedmont loblolly pine plantations. U.S. Dep. Agric. For. Serv., Res. Note SE-233, 4 p. Southeast. For. Exp. Stn., Asheville, N.C.

On the Hitchiti Experimental Forest, loblolly pines (*Pinus taeda*) were planted following clearcutting and slash burning. Green fuel (grasses, herbs, and vines) accumulation in loblolly pine plantations is given (graph).

381. BRITTON, CARLTON M., and HENRY A. WRIGHT. 1971. Correlation of weather and fuel variables to mesquite damage by fire. J. Range Manage. 24:136–141.

Grass production with and without burning mesquite (*Prosopis glandulosa*) overstory is given for a study area in Texas.

382. BROCK, JOHN H., R. H. HAAS, and J. C. SHAVER. 1978. Zonation of herbaceous vegetation associated with honey mesquite in north-central Texas. *In* Proc. First Int. Rangeland Cong. p. 187–189. Denver, Colo.

*Prosopis glandulosa* overstory was reduced by chemical and mechanical methods. Understory compositions are presented in graphic form and understory production data are given in tabulated form.

383. BYRD, NATHAN A., and CLIFFORD E. LEWIS. 1967. Managing southern pine forests to produce forage for beef cattle. USDA For. Serv., Southeast. Area, State and Private For., For. Manage. Bull. Atlanta, Ga.

Relationship between pounds of forage and percent tree canopy is presented in graphic form for southern pine forests. Forage production under different forage stand ages is given in tabular form.

384. CAMPBELL, R. S. 1946. Determination of grazing values of native vegetation of southern pine forest ranges. Ecology 27:195–204.

Herbage production under different overstory communities is given for a study area on the Kisatchie National Forest, La. The major overstory trees include longleaf (*Pinus palustris*) and slash pine (*P. caribaea*) and blackjack oak (*Quercus marilandica*).

385. CAMPBELL, ROBERT S. 1955. Vegetational changes and management in the cutover longleaf-slash pine area of the Gulf Coast. Ecology 36:29–34.

A literature review, including examples of changes in herbaceous understory vegetation as related to timber cutting, burning, and grazing, is presented for the Coastal Plain.

386. CAMPBELL, ROBERT S., and JOHN T. CASSADY. 1949. Determining forage weight on southern forest ranges. J. Range Manage. 2:30–32.

Grass production under longleaf pine forest overstory is described for Louisiana.

387. CAMPBELL, ROBERT S., and JOHN T. CASSADY. 1951. Grazing values for cattle on pine forest ranges in Louisiana. La. Agric. Exp. Stn., Baton Rouge, Bull. 452, 31 p.
Grass production associated with different forest grazing types is presented in tabular form. Grazing types considered include creek bottom hardwoods, loblolly pine-hardwoods, scrub oak, longleaf pine, open forest, and grassland.
388. CASSADY, JOHN T. 1951. Bluestem range in the piney woods of Louisiana and east Texas. J. Range Manage. 4:173-177.
Grass production under different forest overstory stand conditions and species composition is given. Overstory is dominated by longleaf pine and slash pine.
389. CASSADY, JOHN T. 1952. Grass production doubled by control of scrub oak. J. For. 50:462-463.
In Louisiana, grass production is presented (tables) after controlling (girdling and poisoning with Ammate) blackjack (*Quercus marilandica*) and post oak (*Q. stellata*) overstory.
390. CLARY, WARREN P. 1979. Grazing and overstory effects on rotationally burned slash pine plantation ranges. J. Range Manage. 32:264-266.
A relationship between herbage production and *Pinus elliottii* is given in equation form for central Louisiana.
391. COX, AMURICE, and HARRY M. ELWELL. 1944. Brush removal for pasture improvement. Agric. Eng. 25:253-261.
Grass densities under various amounts of blackjack and white oak canopy are given (table) for a study site in central Oklahoma.
392. CRAWFORD, HEWLETTE S. 1960. Effect of aerial 2,4,5-T sprays on forage production in west-central Arkansas. J. Range Manage. 13:44.
A table describing grass, forb, and browse production under sprayed (2,4,5-T) and unsprayed stands of post (*Quercus stellata*) and blackjack oak (*Q. marilandica*), and hickories (*Carya* spp.) is presented for a study area in the Ozark Mountains.
393. CRAWFORD, HEWLETTE S., JAMES B. WHELAN, RICHARD F. HARLOW, and JOHN E. SKEEN. 1975. Deer range potential in selective and clearcut oak-pine stands in southwestern Virginia. U.S. Dep. Agric. For. Serv., Res. Pap. SE-134, 12 p. Southeast. For. Exp. Stn., Asheville, N.C.
Amounts of understory production in selective and clearcut pitch pine (*Pinus rigida*) and oak (*Quercus* spp.) stands in the Jefferson National Forest are compared (tables).
394. CUSHWA, CHARLES T., ERNST V. BRENDER, and ROBERT W. COOPER. 1966. The response of herbaceous vegetation to prescribed burning. U.S. Dep. Agric. For. Serv., Res. Note SE-53, 2 p. Southeast. For. Exp. Stn., Asheville, N.C.
Herbaceous plant response to burning of loblolly pine (*Pinus taeda*) overstory is described (tables) for a study area on the Hitchiti Experimental Forest in Georgia.
395. CUSHWA, CHARLES T., MELVIN HOPKINS, and BURL S. McGINNES. 1970. Reponse of legumes to prescribed burns in loblolly pine stands of the South Carolina Piedmont. U.S. Dep. Agric. For. Serv., Res. Note SE-140, 6 p. Southeast. For. Exp. Stn., Asheville, N.C.
The frequency of occurrence of leguminous plants before and after burning on study sites dominated by loblolly pine (*Pinus taeda*) overstory is given in tabular form.
396. CUSHWA, CHARLES T., and M. B. JONES. 1969. Wildlife food plants on chopped areas in the Piedmont of South Carolina. U.S. Dep. Agric. For. Serv., Res. Note SE-119, 4 p. Southeast. For. Exp. Stn., Ashville, N.C.
The frequency of occurrence and abundance of leguminous plants and herbaceous plants other than legumes on study areas where loblolly pine overstory has been clearcut and chopped (drum chopper) or left uncut are presented in tabular form.
397. CUSHWA, CHARLES T., and JOHN B. REDD. 1966. One prescribed burn and its effect on habitat on the Powhatan game management area. U.S. Dep. Agric. For. Serv., Res. Note SE-61, 2 p. Southeast. For. Exp. Stn., Asheville, N.C.
A comparison among number, kind, and production of game food plants in cut, burned, and untreated pine stands in the Piedmont of Virginia is given in tabular form.
398. DAHL, B. E., R. E. SOSEBEE, J. P. GOEN, and C. S. BRUMLEY. 1978. Will mesquite control with 2,4,5-T enhance grass production? J. Range Manage. 31:129-131.
Effect of controlling *Prosopis glandulosa* was studied in western Texas. Response of herbaceous understory, primarily *Buchloe dactyloides* and *Hilaria mutica*, is given in tabular form.
399. DALRYMPLE, R. L., DON D. DWYER, and P. W. SANTLEMANN. 1964. Vegetational responses following winged elm and oak control in Oklahoma. J. Range Manage. 17:249-253.
Herbage yields under overstory that was killed (2,4,5-T) or left alive are presented in tabular form. Overstory is dominated by blackjack (*Quercus marilandica*) and post oak (*Q. stellata*) and winged elm (*Ulmus alata*).
400. DANIELL, JEFF W., and W. S. HARDCASTLE. 1972. Response of peach trees to herbicide and mechanical weed control. Weed Sci. 20:133-136.
Orchards of 1- and 2-year-old peach trees (*Prunus persica*) were treated with preemergence herbicides (simazine, dichlobenil, natralin, CP-44939, and alachlor) and postemergence herbicides (paraquat, terbacil, diphenamid, dinoseb, and chloropropham plus dinoseb plus PPG-124) at Experiment and Fort Valley, Ga. Broadleaf and grass weed control was evaluated in tabular form.
401. DARROW, ROBERT A., and WAYNE G. McGULLEY. 1959. Brush control and range improvement in the post oak-blackjack oak area of Texas. Tex. Agric. Exp. Stn., College Station, Bull. 942, 16 p.
Forage yields and composition on post oak-blackjack oak woodlands subjected to partial and compete removal (mechanical and chemical) of overstory are compared (tables) to undisturbed sites.
402. DODD, J. D., and S. T. HOLTZ. 1972. Integration of burning with mechanical manipulation of south Texas grassland. J. Range Manage. 25:130-136.
Herbage production following removal of mesquite (*Prosopis glandulosa*) and other brush species is presented (graphs).
403. DRAWE, D. LYNN. 1977. A study of five methods of mechanical brush control in south Texas. Rangeman's J. 4:37-39.
Herbage production with and without control of mixed brush overstory is graphically presented.

404. DUVALL, V. L., and L. K. HALLS. 1962. Outlook for beef cattle on southern forest ranges. Proc. Soc. Am. For. 1962:76–79.

Herbaceous growth under different timber conditions and prescribed burning schedules is given (table) for longleaf and slash pine stands in the Eastern Gulf and Atlantic Coastal States.

405. DUVALL, V. L., and J. B. HILMON. 1965. New grazing research programs for southern forest ranges. J. Range Manage. 18:132–136.

Average herbage yields under heavily stocked longleaf pine and slash pine stands, and where stands are scattered or absent, are given for the Coastal Plain, from east Texas to South Carolina.

406. DUVALL, VINSON L., and HAROLD E. GRELEN. 1967. Fertilization uneconomic for forage improvement in Louisiana pine plantations. U.S. Dep. Agric. For. Serv., Res. Note SO-51, 3 p. South. For. Exp. Stn., New Orleans, La.

Herbage yield and quality associated with different fertilizer treatments (N, P, and K) applied on slash pine (*Pinus elliottii*) plantations are described in tabular form.

407. ELWELL, HARRY M. 1953. New herbicide controlled oak brush and resulted in increased native grass production. Weeds 2:302–303.

The increase in production of native grasses following chemical control (2,4,5-T) of post oak and blackjack oak is described for a study area at the Red Plains Conservation Experiment Station, Okla.

408. ELWELL, HARRY M. 1960. Land improvement through brush control. Soil Conserv. 26:56–59.

Production of native grasses with and without chemical control (2,4,5-T) of woody overstory is described for Oklahoma and nearby States. Overstory species include post, blackjack, and dwarf chinquapin oaks and scrub hickory.

409. ELWELL, HARRY M. 1964. Oak brush control improves grazing lands. Agron. J. 56:411–415.

Native grass yields are presented (table) with and without control (2,4,5-T) of overstory dominated by post (*Quercus stellata*), blackjack (*Q. marilandica*), and dwarf chinquapin oak (*Q. prinoides*) for study areas throughout eastern Oklahoma.

410. FITZGERALD, C. H., R. F. RICHARDS, C. W. SELDEN, and J. T. MAY. 1975. Three-year effects of herbaceous weed control in a sycamore plantation. Weed Sci. 23:32–35.

On the Piedmont Plateau in Georgia, American sycamore (*Plantanus occidentalis*) were planted and treated with simazine, atrazine, dalapon, and ametryne herbicides. Percent weed control and sycamore survival during the first growing season are shown (tables).

411. GAINES, E. M., R. S. CAMPBELL, and J. J. BRASINGTON. 1954. Forage production on longleaf pine stands of southern Alabama. Ecology 35:59–62.

A polynomial predicting equation describes herbage production as a function of forest overstory density. Also, a linear equation relating herbage production to forest overstory litter is given. The overstory is dominated by longleaf pine (*Pinus palustris*).

412. GEORGE, JAMES F., and JEFF POWELL. 1979. Cattle grazing impacts on small cleared areas in dense American elm woodlands. J. Range Manage. 32:78–79.

Herbaceous data are given in graphic form for an *Ulmus americana* overstory in Oklahoma.

413. GILLS, GARY G. 1970. Effects of prescribed burning on deer browse. J. Wildl. Manage. 34:540–545.

Available browse is graphically illustrated for burned and unburned study areas on the Cumberland Plateau in Tennessee. Shortleaf pine (*Pinus echinata*) was the predominant pine species, and white (*Quercus alba*) and chestnut oak (*Q. prinus*), the predominant hardwood species.

414. GOLDEN, MICHAEL S. 1979. Forest vegetation of the lower Alabama Piedmont. Ecology 60:770–782.

Presence data for understory shrubs and herbs are given for a number of *Quercus-Pinus* stands.

415. GONZALEZ, C. L., and J. D. DODD. 1979. Production response of native and introduced grasses to mechanical brush manipulation, seeding and fertilization. J. Range Manage. 32:305–309.

Tabular and graphic data show herbage yield with and without mechanical control of *Leucophyllum frutescens, Acacia rigidula, Karwinskia humboldtiana, Bumelia celastrina, Prosopis glandulosa*, and *Schaefferia cuneifolia*. Investigations were on the Rio Grande Plain of Texas.

416. GRANO, CHARLES X. 1970. Small hardwoods reduce growth of pine overstory. U.S. Dep. Agric. For. Serv., Res. Pap SO-55, 9 p. South. For. Exp. Stn., New Orleans, La.

In Arkansas, the growth of loblolly (*Pinus taeda*) and shortleaf pine (*P. echinata*) before and after control (2,4,5-T) of a hardwood understory is graphically illustrated.

417. GREENE, S. W. 1935. Relation between winter grass fires and cattle in the longleaf pine belt. J. For. 33:338–341.

Increases in forage production after burning longleaf pine on the McNeill Experimental Area in Mississippi are described.

418. GRELEN, H. E., and E. A. EPPS, JR. 1967. Herbage response to fire and litter removal on southern bluestem range. J. Range Manage. 20:403–404.

Periodic herbage yields after burning and mowing sites clearcut of longleaf pine (*Pinus palustris*) overstory are given (table) for a study area in central Louisiana.

419. GRELEN, H. E., L. B. WHITAKER, and R. E. LOHREY. 1972. Herbage response to precommercial thinning in direct-seeded slash pine. J. Range Manage. 25:435–437.

On the Palustris Experimental Forest in central Louisiana, slash pine (*Pinus elliottii*) were thinned to varying densities. The linear relationship between herbage production and pine basal area is given (graph and table).

420. GRELEN, HAROLD E. 1975. Vegetative response to twelve years of seasonal burning on a Louisiana longleaf pine site. U.S. Dep. Agric. For. Serv., Res. Note SO-192, 4 p. South. For. Exp. Stn., New Orleans, La.

Herbage yield after 12 years of biennial burning of longleaf pines (*Pinus palustris*) is graphically illustrated. No significant differences in herbage yield were found among burning treatments and an unburned control.

421. GRELEN, HAROLD E. 1976. Responses of herbage, pines, and hardwoods to early and delayed burning in a young slash pine plantation. J. Range Manage. 29:301–303.

The relation of herbage yield to slash pine (*Pinus elliottii*) plantation age is described (graph) in central Louisiana.

422. GRELEN, HAROLD E. 1978. Forest grazing in the South. J. Range Manage. 31:244–250.

Herbaceous understory-forest overstory relationships are described for southern and southeastern United States. Forest overstories are predominantly *Pinus* spp. and *Quercus* spp.

423. GRELEN, HAROLD E. 1978. Winter and spring prescribed fires on Louisiana pine-bluestem range. *In* Proc. First Int. Rangeland Cong. p. 242–244. Denver, Colo.

Herbage yields are given for *Pinus elliottii* plantations of different ages. Data are presented in graphic form.

424. GRELEN, HAROLD E., and HANS G. ENGHARDT. 1973. Burning and thinning maintain forage in a longleaf pine plantation. J. For. 71:419–425.

Average herbage yields after prescribed burning and thinning of southern waxmyrtle (*Myrica cerifera*), blackjack oak (*Quercus marilandica*), blackgum (*Nyssa sylvatica*), and flowering dogwood (*Cornus florida*) in the Palustris Experimental Forest in Louisiana are graphically illustrated.

425. GRELEN, HAROLD E., and RICHARD E. LOHREY. 1978. Herbage yield related to basal area and rainfall in a thinned longleaf plantation. U.S. Dep. Agric. For. Serv., Res. Note SO-232. 4 p. South. For. Exp. Stn., New Orleans, La.

A relationship of an herbaceous understory (primarily *Andropogon scoparius*) to a *Pinus palustris* overstory in central Louisiana is presented by graphs and equations.

426. HALLS, L. K. 1973. Flowering and fruiting of southern browse species. U.S. Dep. Agric. For. Serv., Res. Pap. SO-90, 10 p. South. For. Exp. Stn., New Orleans, La.

Flowering and fruiting dates are reported for 14 browse species growing in the open and beneath trees in an east Texas pine-hardwood forest. Predominant overstory species are shortleaf (*Pinus echinata*) and loblolly (*P. taeda*) pines.

427. HALLS, L. K., and R. ALCANIZ. 1971. Forage yields in an east Texas pine-hardwood forest. J. For. 69:25–26.

Forage yield increased in a mature, upland pine-hardwood forest after thinning and prescribed burning. The forest is dominated by shortleaf (*Pinus enchinata*) and loblolly pine (*P. taeda*), with a midstory of southern red (*Quercus falcata*) and post oak (*Q. stellata*), hickories (*Carya spp.),* and sweetgum *(Liquidambar styraciflua*).

428. HALLS, L. K., and R. ALCANIZ. 1972. Growth patterns of deer-browse plants in southern forests. U.S. Dep. Agric. For. Serv., Res. Pap. SO-75, 14 p. South. For. Exp. Stn., New Orleans, La.

Growth rates for browse plants growing in the open and under a forest canopy are graphically illustrated. Studies were conducted near Nacogdoches, Tex., in a stand of shortleaf (*Pinus echinata*) and loblolly (*P. taeda*) pines mixed with hardwoods.

429. HALLS, L. K., and H. S. CRAWFORD. 1965. Vegetation response to an Ozark woodland spraying. J. Range Manage. 18:338–340.

Tables of grass, forb, and browse yields under sprayed (2,4,5-T) and unsprayed stands of post (*Quercus stellata*) and blackjack oak (*Q. marilandica*) are presented for a study area in west-central Arkansas.

430. HALLS, L. K., O. M. HALE, and B. L. SOUTHWELL. 1956. Grazing capacity of wiregrass-pine ranges of Georgia. Ga. Agric. Exp. Stn., Athens, Tech. Bull. N.S. 2, 38 p.

The relation of grass production to *Pinus palustris* and *P. elliottii* canopy and basal area is given in graphic, equation, and tabular forms for the Alapaha Experimental Range.

431. HALLS, L. K., and W. B. HOMESLEY. 1966. Stand composition in a mature pine-hardwood forest of southeastern Texas. J. For. 64:170–174.

Crown cover, frequency, and density of understory vegetation associated with burned-over loblolly-shortleaf pine-hardwood stands are presented (tables and graphs) for a study area on the San Jacinto Experimental Forest.

432. HALLS, L. K., and R. F. SUMAN. 1954. Improved forage under southern pines. J. For. 52:848–851.

A relationship between herbaceous growth and tree canopy under different site conditions and fertilizer treatments is graphically presented for a study area in southern Georgia. Overstory is dominated by longleaf (*Pinus palustris*) and slash pine (*P. elliottii*) of pole and small sawtimber size.

433. HALLS, LOWELL K. 1955. Grass production under dense longleaf-slash pine canopies. U.S. Dep. Agric. For. Serv., Res. Note 83, 2 p. Southeast. For. Exp. Stn., Asheville, N.C.

Grass production declines as overhead longleaf pine and slash pine canopies increase, as graphically illustrated for a study area on the Alapaha Experimental Range in Georgia.

434. HALLS, LOWELL K. 1970. Growing deer food amidst southern timber. J. Range Manage. 23:213–215.

A literature review, including a summary of the influence of forest overstories on forage production, is presented for the pine-hardwood forests of the South.

435. HALLS, LOWELL K. 1973. Managing deer habitat in loblolly-shortleaf pine forest. J. For. 71:752–757.

Average forage production in relation to forest density is described. Results apply to much of the loblolly-shortleaf pine-hardwood forest from Virginia to east Texas and Oklahoma. Major overstory species are *Pinus echinata, P. taeda, Liquidambar styraciflua, Quercus* spp., *Carya* spp., and *Ulmus* spp.

436. HALLS, LOWELL K. 1974. Deer browse growth reduced by pine overstory. Southeast. Assoc. Game and Fish Comm. Proc. 27:304–306.

Table values are given for shrub growth under two levels of *Pinus echinata* and *P. taeda* overstory in east Texas.

437. HALLS, LOWELL K., and HEWLETTE S. CRAWFORD, JR. 1960. Deer-forest habitat relationships in north Arkansas. J. Wildl. Manage. 24:387–395.

The production and availability of forage, as influenced by timber types, age class, crown closure, and grazing, are discussed. Timber types include oak-hickory, cedar-greenbrier, and pine-oak.

438. HALLS, LOWELL K., and JOSEPH L. SCHUSTER. 1965. Tree-herbage relations in pine-hardwood forest of Texas. J. For. 63:282–283.

Logarithmic equations describe grass and herbage production as functions of expressions of forest overstory density. The main tree species forming the overstory are loblolly (*Pinus taeda*) and shortleaf pine (*P. echinata*), southern red (*Quercus falcata*) and post oak (*Q. stellata*), sweetgum (*Liquidambar styraciflua*), and hickories (*Carya* spp.).

439. HARLOW, RICHARD F. 1976. Plant response to thinning and fencing a hydric hammock and cypress pond in central Florida. U.S. Dep. Agric. For. Ser., Res. Note SE-230, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

Two study areas, a hydric hammock dominated by longleaf pine (*Pinus palustris*), slash pine (*P. elliottii*), and cabbage palmetto (*Sabal palmetto*) and a cypress pond dominated by *Taxodium distichum* var. *nutans* were treated in 3 ways: fenced and thinned, fenced and unthinned, and unfenced and unthinned. Number, coverage, and utilization of woody plants by deer for the two study areas are given (tables).

440. HARLOW, RICHARD F., PAUL A. SHRAUDER, and MONTE E. SEEHORN. 1975. Deer browse resources of the Chattahoochee National Forest. U.S. Dep. Agric. For. Serv., Res. Pap. SE-136, 16 p. Southeast. For. Exp. Stn., Asheville, N.C.

Browse (choice and other) for 14 forest types in the Chattahoochee National Forest is shown (tables).

441. HART, RICHARD H., RALPH H. HUGHES, CLIFFORD E. LEWIS, and WARREN G. MONSON. 1970. Effect of nitrogen and shading on yield and quality of grasses grown under young slash pines. Agron. J. 62:285-287.

The yield of planted grasses under slash pine (*Pinus elliottii*) overstory after treatment with different rates of nitrogen fertilization is presented (table and graph) for a study area on the Coastal Plains of Georgia.

442. HEIRMAN, ALAN L., and HENRY A. WRIGHT. 1973. Fire in medium fuels of west Texas. J. Range Manage. 26:331-335.

Herbage yields following prescribed burning of honey mesquite (*Prosopis glandulosa*) and velvet mesquite (*P. velutina*) near Lynn County, Tex., are given in tabular form.

443. HODGKINS, EARL J. 1958. Effects of fire on undergrowth vegetation in upland southern pine forests. Ecology 39:36-46.

A literature review, including a description of the change in understory vegetation following burning upland southern pine forests, is presented for an experimental area in northwestern Alabama.

444. HOOK, DONALD D., and JACK STUBBS. 1967. An observation of understory growth retardation under three species of oak. U.S. Dep. Agric. For. Serv., Res. Note SE-70, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

The degree of understory vegetation commonly associated with seven species of seed trees is presented (table) for the Santee Experimental Forest in South Carolina.

445. HUGHES, RALPH H. 1975. The native vegetation in south Florida related to month of burning. U.S. Dep. Agric. For. Serv., Res. Note SE-222, 8 p. Southeast. For. Exp. Stn., Asheville, N.C.

On the Corkscrew Experimental Forest and the Caloosa Experimental Range, plots without trees and ranges dominated by slash pine (*Pinus elliottii*) were burned in October, November, January, March, and May. Herbage yields 30 days, 60 days, and 2 years following treatments on both study areas are graphically illustrated.

446. HUGHES, RALPH H., GEORGE W. BENGTSON, and THADDEUS A. HARRINGTON. 1971. Forage response to nitrogen and phosphorus fertilization in a 25-year-old plantation of slash pine. U.S. Dep. Agric. For. Serv., Res. Pap. SE-82, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

Production of herbaceous vegetation following the application of fertilizer to an old-field plantation of slash pine (*Pinus elliottii*) near Olustee, Fla., is graphically illustrated.

447. JOHNSON, A. SYDNEY, and J. LARRY LANDERS. 1978. Fruit production in slash pine plantations in Georgia. J. Wildl. Manage. 42:606-613.

Production of fleshy fruits and hard mast is described in graphs and tabular form for *Pinus elliottii* plantations of different ages on the Georgia Coastal Plain flatwoods.

448. LAESSLE, ALBERT M. 1965. Spacing and competition in natural stands of sand pine. Ecology 46:65-72.

The density of ground cover and spacing of sand pine (*Pinus clausa*) canopy trees in Florida are discussed.

449. LAY, DANIEL W. 1956. Effects of prescribed burning on forage and mast production in southern pine forest. J. For. 54:582-584.

Forage production on burned and unburned pine-hardwood sites is described (tables) for a study area in southeast Texas.

450. LAY, DANIEL W. 1957. Browse quality and the effects of prescribed burning in southern pine forests. J. For. 55:342-347.

The percent of forage in browse is given (table) by date and burning history (burned or unburned) for a loblolly pine forest on the Siecke State Forest in Texas.

451. LAY, DANIEL W. 1967. Browse palatability and the effects of prescribed burning in southern pine forests. J. For. 65:826-828.

Availability of deer browse before and after prescribed burning of longleaf pine is given (table) for a study site on the Siecke State Forest in Texas.

452. LEMON, PAUL C. 1949. Successional responses of herbs in the longleaf-slash pine forest after fire. Ecology 30:135-145.

Changes in density of herbaceous understory on areas having different fire histories are described (tables) for a study area on the Alapaha Experimental Range in Georgia. The forest cover is second-growth longleaf pine and slash pine.

453. LEWIS, CLIFFORD E. 1964. Forage response to month of burning. U.S. Dep. Agric. For. Serv., Res. Note SE-35, 4 p. Southeast. For. Exp. Stn., Asheville, N.C.

A relationship between herbage yield and time of burning of cutover pine-palmetto flatwoods is described (table and graphs) for study areas in southern Florida.

454. LEWIS, CLIFFORD E. 1974. Grazing considerations in managing young pines. *In* Proc. Symposium on Management of Young Pines. p. 160-170. U.S. Dep. Agric. For. Serv., Southeast Area, State and Private Forestry, and South. and Southeast. For. Exp. Stn.

Information from the southern and southeastern United States concerning herbage production related to pine (*Pinus* spp.) canopy, basal area, and tree age is given in tabular and graphic forms.

455. LEWIS, CLIFFORD E., and THOMAS J. HARSHBARGER. 1976. Shrub and herbaceous vegetation after 20 years of prescribed burning in the South Carolina coastal plain. J. Range Manage. 29:13-18.
In the Santee and Westvaco Experimental Forests, six burn treatments (annual winter and summer, periodic winter and summer, biennial summer, and no burn) were applied to loblolly pine and hardwood stands to determine treatment effects on forbs, grasses, and grasslike and woody plants. Ground cover and herbage production increases are illustrated (tables and graphs).

456. LEWIS, CLIFFORD E., and RICHARD H. HART. 1972. Some herbage responses to fire on pine-wiregrass range. J. Range Manage. 25:209-213.
Relation of herbage yields to gallberry (*Ilex glabra*) cover (following fire) is discussed (tables) for the Alapaha Experimental Range, Ga.

457. MAYEUX, H. S., JR., D. L. DRAWE, and C. J. SCIFRES. 1979. Control of common goldenweed with herbicides and associated forage release. J. Range Manage. 32:271-274.
Herbage production with and without herbicidal control of *Isocoma coronopifolia* is given in tabular form for south Texas.

458. McCALEB, J. E., E. M. HODGES, and C. L. DANTZMAN. 1961. Effect of herbicidal control of saw-palmetto on associated native forage plants in peninsular Florida. J. Range Manage. 14:126-130.
Yields of grasses, forbs, and shrubs are related (tables) to percent kill and percent canopy reduction after spraying saw palmetto with various herbicides.

459. McDANIEL, K. C., R. H. HASS, and J. H. BROCK. 1978. Range condition trends following control of honey mesquite (*Prosopis glandulosa*) on deep hardlands in north-central Texas. *In* Proc. First Int. Rangeland Cong. p. 530-533. Denver, Colo.
Descriptions of understory beneath overstories reduced by chemical and mechanical methods are presented in tabular form.

460. McKINLEY, CAROL E., and FRANK P. DAY, JR. 1979. Herbaceous production in cut-burned, uncut-burned, and control areas of a *Chamaecyparis thyroides* (L.) BSP (Cupressaceae) stand in the Great Dismal Swamp. Bull. Torrey Bot. Club 106:20-28.
Herbage biomass data are presented graphically and in tables. Study was conducted in North Carolina.

461. MOORE, WILLIAM H. 1974. Some effects of chopping saw-palmetto-pineland threeawn range in south Florida. J. Range Manage. 27:101-104.
The effect of control of *Serenoa repens* on the production of herbage is presented in tabular form.

462. MYERS, CLIFFORD A. 1977. Simulating timber and deer food potential in loblolly pine plantations. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. SO-12, 29 p. South. For. Exp. Stn., New Orleans, La.
Equations are given to describe the relationship between grass and forb production and the age of *Pinus taeda* plantations in eastern Texas.

463. NEEL, L. R. 1939. The effect of shade on pasture. Tenn. Agric. Exp. Stn., Circ. 65, 2 p.
Tests at the Middle Tennessee Experiment Station suggest that the presence of well-managed walnut and locust trees may improve the production of seeded forage plants. Tabular values show cattle gains on pastures with and without trees.

464. OOSTING, HENRY J. 1944. The comparative effect of surface and crown fire on the composition of a loblolly pine community. Ecology 25:61-69.
Density, frequency, and basal area of shrubs and woody vines found in three areas of a loblolly pine (*Pinus taeda*) stand subjected to surface fire or crown fire, or unburned are described (table) for a study area on the Duke Forest in North Carolina. Also, the change in frequencies of herbs is given for the three areas.

465. PARKER, KENNETH W., and W. G. McGINNES. 1941. Mesquite: the silent invader. The Cattleman 27(12):35,38-40.
A literature review, including a description of relationships between perennial grass cover and mesquite overstory, is presented for Texas.

466. PATTON, DAVID R., and BURD S. McGINNES. 1964. Deer browse relative to age and intensity of timber harvest. J. Wildl. Manage. 28:458-463.
Logarithmic equations describe production of available browse as a function of overstory thinning intensity and age of cut in Virginia. Overstory components include white (*Quercus alba*), scarlet (*Q. coccinea*), chestnut (*Q. primus*), and black oak (*Q. velutina*), and Virginia (*Pinus virginiana*) and pitch pine (*P. rigida*).

467. PEARSON, H. A. 1974. Range and wildlife opportunities. *In* Proc. Symposium on Management of Young Pines. p. 19-27. U.S. Dep. Agric. For. Serv., Southeast. Area, State and Private Forestry, and South. and Southeast. For. Exp. Stns.
Herbage yields related to age of southern pine (*Pinus* spp.) plantations are given in tabular form for Louisiana.

468. PEARSON, H. A. 1974. Utilization of a forest grassland in southern United States. *In* Proc. 12th Int. Grassland Cong. (Sec. 5). p. 543-547.
Herbage production under different ages of slash pine (*Pinus elliottii*) plantations in Louisiana is given.

469. PEARSON, H. A. 1975. Exotic grass yields under southern pines. U.S. Dep. Agric. For. Serv., Res. Note SO-201, 3 p. South. For. Exp. Stn., New Orleans, La.
Production of exotic and native forage species under slash (*Pinus elliottii*) and loblolly (*P. taeda*) pine is given in tabular form for the Palustris Experimental Forest in central Louisiana.

470. PEARSON, H. A., and L. B. WHITAKER. 1974. Forage and cattle responses to different grazing intensities on southern pine range. J. Range Manage. 27:444-446.
Data given in tabular and graphic form describe the decline of herbage production with increased age of slash pine (*Pinus elliottii*) plantations on the Palustris Experimental Forest in central Louisiana.

471 PEARSON, H. A., and L. B. WHITAKER. 1974. Yearlong grazing of slash pine ranges: effects on herbage and browse. J. Range Manage. 27:195-197.
A linear relationship is described between herbage yield and crown cover of slash pine for the Palustris Experimental Forest in central Louisiana.

472. PETTIT, R. D. 1979. Effects of picloram and tebuthiuron pellets on sand shinnery oak communities. J. Range Manage. 32:196-200.
Production of herbaceous understory is given for control and herbicide treatment of *Quercus havardii* in west Texas.

473. POWELL, JEFF, and THADIS W. BOX. 1967. Mechanical control and fertilization as brush management practices affect forage production in south Texas. J. Range Manage. 20:227–236.

Graphs of herbage yields with and without mechanical control of a complex of brush overstory species are presented.

474. RAY, HURLON C. 1958. Aerial chemical reduction of hardwood brush as a range improvement practice in Arkansas. J. Range Manage. 11:284–290.

Percent increase of native grass production as related to percent kill (2,4,5-T) of hardwood overstory is presented in tabular form.

475. READ, RALPH A. 1951. Woodland forage in the Arkansas Ozarks. J. Range Manage. 4:391–396.

A relationship between herbage production and forest (primarily oak-hickory) overstory density is described graphically for upland hardwood range in the Ozarks.

476. RHODES, ROBERT R. 1952. Timber and forage production in a pine-hardwood stand in Texas. J. For. 50:456–459.

Relationship between forage production and forest overstory density is graphically illustrated. Forest composition is predominantly loblolly pine, shortleaf pine, post oak, southern red oak, and hickories.

477. RUSSELL, T. E. 1969. Underplanting shortleaf pine. For. Farmer 29:10–17.

Growth and survival of underplanted shortleaf pine after release (girdle, 2,4,5-T) of hardwood overstory are discussed.

478. SCHULTZ, ROBERT P. 1976. Environmental change after site preparation and slash pine planting on a flatwoods site. U.S. Dep. Agric. For. Serv., Res. Pap. SE-156, 20 p. Southeast. For. Exp. Stn., Asheville, N.C.

In Baker County, Fla., slash pine (*Pinus elliottii*) planting sites dominated by shrubs (*Serenoa repens* and *Ilex glabra*) were burned, burned and disked, and burned, disked, and bedded. Weights and frequencies of understory vegetation before and 2 years following site preparation are given (tables).

479. SCHUSTER, JOSEPH L. 1967. The relation of understory vegetation to cutting treatments and habitat factors in an east Texas pine-hardwood type. Southwest. Nat. 12:339–364.

The composition, frequency, and production of understory vegetation associated with various stands of loblolly-shortleaf pine-hardwood forest are described in tabular form.

480. SCHUSTER, J. L., and L. K. HALLS. 1963. Timber overstory determines deer forage in shortleaf-loblolly pine-hardwood forests. Proc. Soc. Am. For. 1962:165–167.

Forage production associated with pine-hardwood forest stands cut by various silvicultural systems is presented (table) for a study area on the Kurth Experimental Forest in Texas.

481. SCIFRES, C. J. 1972. Herbicide interactions in control of sand shinnery oak. J. Range Manage. 25:386–389.

Data are presented in tabular form to illustrate changes in grass production following control (silvex, 2,4,5-T, picloram, and dicamba combinations) of *Quercus havardii* in Texas.

482. SCIFRES, C. J. 1975. Fall application of herbicides improves McCartney rose-infested coastal prairie rangelands. J. Range Manage. 28:483–486.

Grass production is described under conditions of no control, spraying, and spraying and burning of *Rosa bracteata* on the Texas Coastal Prairie.

483. SCIFRES, C. J., and D. B. POLK, JR. 1974. Vegetation response following spraying a light infestation of honey mesquite. J. Range Manage. 27:462–465.

Herbage production with and without the presence of *Prosopis glandulosa* is given in tabular form for a site in Texas.

484. SCIFRES, C. J., J. H. BROCK, and R. R. HAHN. 1971. Influence of secondary succession on honey mesquite invasion in North Texas. J. Range Manage. 24:206–210.

Herbage production on a 30-year protected exclosure and an adjacent grazed area of honey mesquite (*Prosopis glandulosa*) is described. Percentage composition, frequency, and pounds per acre of the three dominant grasses on both study sites are shown (tables).

485. SCIFRES, C. J., and J. L. MUTZ. 1978. Herbaceous vegetation changes following applications of tebuthiuron for brush control. J. Range Manage. 31:375–378.

Change in herbaceous production was evaluated on the south Texas plains following herbicide control of mixed brush stands (*Prosopis, Acacia*, and *Aloysia*). Data are presented in tabular form.

486. SCIFRES, C. J., J. L. MUTZ, and G. P. DURHAM. 1976. Range improvement following chaining of south Texas mixed brush. J. Range Manage. 29:418–421.

Grass production and consumption and overstory density are given in tabular form for different chaining treatments. Main overstory species are honey mesquite (*Prosopis glandulosa*), spring hackberry (*Celtis pallida*), and lime prickly ash (*Zanthoxylum fagaro*).

487. SEGELQUIST, CHARLES A., and WALTER E. GREEN. 1968. Deer food yields in four Ozark forest types. J. Wildl. Manage. 32:330–337.

In Arkansas, yield of potential deer food under different forest types is presented in tabular form. Forest types evaluated are upland and hardwood, upland pine-hardwood, cedar glade, and stream-bottom hardwood. Combining all forest types, yield of potential deer food increased linearly with decreasing overstory density.

488. SEGELQUIST, CHARLES A., and RICHARD E. PENNINGTON. 1972. Browse resources of the Ouachita National Forest in Arkansas. U.S. Dep. Agric. For. Serv., Res. Note SO-140, 4 p. South. For. Exp. Stn., New Orleans, La.

Browse yields are given in tabular form for several pine and hardwood overstory conditions.

489. SEGELQUIST, CHARLES A., FRED D. WARD, and ROBERT G. LEONARD. 1969. Habitat-deer relations in two Ozark enclosures. J. Wildl. Manage. 33:511–520.

Five years of summer and late winter vegetation yields are presented tabularly for two exclosures (principal overstory species are *Pinus echinata* and *Quercus* spp.) located on the Sylamore Experimental Forest, Ark.

490. SKROCH, W. A., T. J. SHEETS, and T. J. MONACO. 1975. Weed populations and herbicide residues in apple orchards after 5 years. Weed Sci. 23:53–57.

At the Mountain Horticulture Crops Research Station in North Carolina, apple trees were planted and treated with simazine, diuron, terbacil, paraquat, dichlobenil, and amitrole. Percent control of weeds at three times during the growing season and the botanical composition of a 5-year-old apple orchard as influenced by herbicides and mowing are given (tables).

491. SMEINS, FRED E., TERRY W. TAYLOR, and LEO B. MERRILL. 1976. Vegetation of a 25-year exclosure on the Edwards Plateau, Tex. J. Range Manage. 29:24–29.
Foliar cover is given in tabular form for both herbaceous and woody plants for different stands. Ashe juniper (*Juniperus ashei*) and Vasey skin oak (*Quercus pungens*) were the most abundant woody species.

492. SMITH, L. F., R. S. CAMPBELL, and CLYDE F. BLOUNT. 1955. Forage production and utilization in longleaf pine forests of south Mississippi. J. Range Manage. 8:58–60.
Grass production under dense stands, moderately stocked stands, and open stands of longleaf pine (*Pinus palustris*) overstory is described for the McNeill Experimental Forest.

493. SOSEBEE, RONALD E., W. E. BOYD, and C. S. BRUMLEY. 1979. Broom snakeweed control with tebuthiuron. J. Range Manage. 32:179–182.
Data on grass increase following reduction of *Xanthocephalum sarothae* by a herbicide are given in tabular form. Study was in west Texas.

494. STERRETT, J. P., and R. E. ADAMS. 1977. The effect of forest conversion with herbicides on pine (*Pinus* spp.) establishment, soil moisture and understory vegetation. Weed Sci. 25:521–523.
Data on frequency and density of understory are given (tables) in relation to herbicidal control of *Quercus* stands in Virginia.

495. STRANSKY, J. J., E. S. NIXON, C. L. BURANDT, JR., and R. L. WILLET. 1974. First-year revegetation following timber harvest in east Texas. U.S. Dep. Agric. For. Serv., Res. Note SO-173, 7 p. South. For. Exp. Stn., New Orleans, La.
Herbage characteristics were compared in recently cleared vs. adjacent wooded areas near Nacogdoches, Tex. Overstory dominants were *Pinus taeda, P. echinata, Liquidambar styraciflua*, and *Quercus falcata*.

496. THILL, RONALD E., and GALE L. WOLTERS. 1979. Cattle production on a southern pine-hardwood forest. Rangelands 1:60–61.
Herbage and browse production is given for two levels of *Pinus-Quercus* basal area. Results are from central Louisiana.

497. THROUSDELL, KENNETH B. 1970. Disking and prescribed burning; six-year residual effects on loblolly pine and competing vegetation. U.S. Dep. Agric. For. Serv., Res. Note SE-133, 6 p. Southeast. For. Exp. Stn., Asheville, N.C.
Graphs and a table describe relationships between shrubs and small hardwoods, and loblolly pine (*Pinus taeda*) 6 years after disking and burning were used to control understory vegetation on a study area in the Virginia Coastal Plain.

498. VECKERT, DARRELL N. 1979. Broom snakeweed: effect on shortgrass forage production and soil water depletion. J. Range Manage. 32:216–220.
Tabular production data are given for perennial grasses and *Xanthocephalum sarothae* from studies in west Texas.

499. VOGL, RICHARD J. 1973. Effects of fire on the plants and animals of a Florida wetland. Am. Midl. Nat. 89:334–347.
Portions of the shore (dominated by *Cephalanthus occidentalis*) of Gannet Pond (Tall Timbers Research Station, Fla.) were burned. Herbage yields (percent frequency and kilograms per hectare) for the treated and control shorelines are shown (tables).

500. WAHLENBERG, W. G., S. W. GREENE, and H. R. REED. 1939. Effects of fire and cattle grazing on longleaf stands as studies at McNeill, Mississippi. U.S. Dep. Agric., Tech. Bull. 683, 52 p. Washington, D.C.
The changes in herbaceous vegetation following burning of loblolly pine (*Pinus taeda*) overstory are described in graphs and tables.

501. WHITCOMB, C. E. 1972. Influence of tree root competition on growth response of four cool season turfgrasses. Agron. J. 64:355–359.
In containers at the Ornamental Horticulture Research Facility (University of Florida, Gainesville), grass production under the shade of and in competition with roots of silver maple (*Acer saccharinum*) and honeylocust (*Gleditsia triacanthos*) was measured. Four types of grasses were also grown with no tree root competition in shade and sun. Results are graphically illustrated.

502. WHITCOMB, CARL E., and ELIOT C. ROBERTS. 1973. Competition between established tree roots and newly seeded Kentucky bluegrass. Agron. J. 65:126–129.
A varying number of roots of silver maple (*Acer saccharinum*) and honeylocust (*Gleditsia triacanthos*) were placed in containers at the Ornamental Horticulture Research Facility (University of Florida, Gainesville). Foliage yields of seeded grass for each of the treatments (including no tree root competition) are shown (graphs and tables).

503. WHITTAKER, R. H. 1966. Forest dimensions and production in the Great Smoky Mountains. Ecology 47:103–121.
Production of different plant life-forms associated with a forest overstory of many species, principally hardwoods, is given in tabular form.

504. WILLIAMSON, MALCOLM J. 1964. Burning does not control young hardwoods on shortleaf pine sites in the Cumberland Plateau. U.S. Dep. Agric. For. Serv., Res. Note CS-19, 4 p. Cent. States For. Exp. Stn., Columbus, Ohio.
The density of hardwood understory before and after burning of shortleaf pine is graphically illustrated for a study site in Kentucky.

505. WOLTERS, GALE L. 1971. Multiple use planning on southern slash pine range. Abstr. of Pap., 24th Annu. Meet., Soc. Range Manage., Reno, 1970. p. 19.
Describes average herbage production under different basal areas of slash pine in central Louisiana.

506. WOLTERS, GALE L. 1973. Southern pine overstories influence herbage quality. J. Range Manage. 26:423–426.
Linear relationships of herbage production and chemical composition to pine basal area in central Louisiana are given. Overstory species are longleaf pine (*Pinus palustris*) and slash pine (*P. elliottii*).

507. WOLTERS, GALE L. 1974. Longleaf uniola and spike uniola require shade. J. Range Manage. 27:45–47.
Data and graphic illustration of the relation of artificial shading to *Uniola* spp. production and quality are presented for a site in Louisiana.

508. WOLTERS, GALE L., ALTON MARTIN, JR., and WARREN P. CLARY. 1977. Timber, browse, and herbage on selected loblolly-shortleaf pine-hardwood forest stands. U.S. Dep. Agric. For. Serv., Res. Note SO-223, 9 p. South. For. Exp. Stn., New Orleans, La.
Typical understory and overstory associations, with *Pinus taeda* and *Quercus falcata* the predominant overstory species, are described for north-central Louisiana and southern Arkansas.

509. WOLTERS, GALE L., and RONALD C. SCHMIDTLING. 1975. Browse and herbage in intensively managed pine plantations. J. Wildl. Manage. 39:557–562.
Yields of Mississippi Gulf Coast herbaceous vegetation with different levels of pine basal area are described by exponential equation. Herbage and browse production are given for different intensive culture procedures in pine plantations. Planted pines included slash (*Pinus elliottii*), longleaf (*P. palustris*), and loblolly (*P. taeda*).

510. YOUNG, VERNON A. 1952. More grass with post oak gone. The Cattleman 38(1):35,44.
Density, composition, and condition classes of herbage associated with cut and uncut post oak overstory in southern Texas are discussed.

## Outside the United States

511. ADAMS, S. N. 1976. Sheep grazing in a young Sitka spruce plantation. J. Appl. Ecol. 13:507–511.
To assess the effects of grazing on Sitka spruce (*Picea sitchensis*) in northern Ireland, plots were unfertilized or fertilized, and sheep were allowed to graze on some of the plots. The amount of forage removed by sheep on grazed and ungrazed plots for 5 consecutive years is shown (tables).

512. BAILEY, ARTHUR W. 1970. Barrier effect of the shrub *Elaeagnus commutata* and forage production in central Alberta. J. Range Manage. 23:248–251.
Herbage production under and between shrub overstory of silverberry (*Elaeagnus commutata*) is presented in tabular form.

513. BAILEY, ARTHUR W. 1972. Forage and woody sprout establishment on cleared, unbroken land in central Alberta. J. Range Manage. 25:119–122.
Competition between seeded grasses and sprouts of aspen (*Populus tremuloides*) and several shrubs is discussed.

514. BAILEY, ARTHUR W. 1978. Use of fire to manage grasslands of the Great Plains: northern Great Plains and adjacent forests. *In* Proc. First Int. Rangeland Cong. p. 691–693. Denver, Colo.
Tabulated data are given for herbage production and standing crop of *Populus tremuloides* in central Alberta, Canada.

515. BAILEY, ARTHUR W., and HOWARD G. ANDERSON. 1979. Brush control on sandy rangelands in central Alberta. J. Range Manage. 32:29–32.
Effects of treating *Populus balsamifera, P. tremuloides*, and *Salix* spp. overstories with fire and herbicides on grass and forb production are presented.

516. BAILEY, ARTHUR W., and ROBERT A. WROE. 1974. Aspen invasion in a portion of the Alberta parklands. J. Range Manage. 27:263–266.
Herbage production with and without aspen (*Populus tremuloides*) and willow (*Salix* spp.) overstories is given in tabulated form.

517. BOWES, GARRY G. 1978. Advantages of herbicides for brush control on newly seeded rangeland in western Canada. *In* Proc. First Int. Rangeland Cong. p. 651–653. Denver, Colo.
For *Populus tremuloides* stands in Saskatchewan, Canada, tabulated data are given for understory yields beneath tree stands in openings.

518. FIELD, DAVID I., and ALBRECHT GLATZLE. 1978. Monitoring the Kalahari Desert. *In* Proc. First Int. Rangeland Cong. p. 193–197. Denver, Colo.
In Botswana, woody overstory and understory plant cover and density are presented in tabular form.

519. FORD, E. D., and P. J. NEWBOULD. 1977. The biomass and production of ground vegetation and its relation to tree cover through a deciduous woodland cycle. J. Ecology 65:201–212.
Herbage production was estimated during a sweet chestnut (*Castanea sativa*) coppice cycle in southeastern England. A logarithmic function describes the relationship, which is graphically displayed.

520. GRUNOW, JULIUS O., and OCKERT J. H. BOSCH. 1978. Above ground annual dry matter dynamics of the grass layer in a tree savanna ecosystem. *In* Proc. First Int. Rangeland Cong. p. 229–233. Denver, Colo.
Biomass values for open and canopied sites are given for the *Eragrostis paliens-Burkea* tree savanna in South Africa.

521. HILTON, JAMES E., and ARTHUR W. BAILEY. 1974. Forage production and utilization in a sprayed aspen forest in Alberta. J. Range Manage. 27:375–380.
Tabular data present the effect of aspen (*Populus tremuloides*) overstories on forage production.

522. HIRST, STANLEY N. 1975. Ungulate-habitat relationships in a South African woodland/savanna ecosystem. Wildl. Monogr. 44, 60 p.
Tabular data are presented on shade cover of woody species and ground cover for herbaceous species in different vegetation types.

523. KNOWLES, R. L., B. K. KLOMP, and A. GILLINGHAM. 1973. Trees and grass: an opportunity for the hill-country farmer. New Zealand Farmer, Sept. 13, 1973. (From Kirby, J. M., 1976. A technique for the tropics-forest grazing. World Crops 28:248–251.)
In New Zealand, expected forage production as a percent of open pasture is given (table) for *Pinus radiata* plantations.

524. McLEAN A., T. M. LORD, and A. J. GREEN. 1971. Utilization of the major plant communities in the Similkameen Valley, British Columbia. J. Range Manage. 24:346–351.
Herbage yields associated with climax plant communities are given in tabulated form. Plant communities evaluated include ponderosa pine—Idaho fescue, Douglas-fir—bluebunch wheatgrass, Douglas-fir—Idaho fescue, Douglas-fir—pinegrass, and Idaho fescue-eriogonum.

525. MacLEAN, DAVID A., and ROSS W. WEIN. 1977. Changes in understory vegetation with increasing stand age in New Brunswick forests: species composition, cover, biomass, and nutrients. Can. J. Bot. 55:2818–2831.
Tabular and graphic data are presented for *Pinus banksiana* and hardwood (*Prunus, Acer, Populus*, and *Betula*) stands.

526. MAIGNAN, FERAULD. 1978. Productivity of *Lolium rigidum* in a forest of oak trees (*Quercus suber*). *In* Proc. First Int. Rangeland Cong. p. 239–241. Denver, Colo.
Understory yields under oak overstories in Morocco are presented in tabulated form.

527. McQUEEN, D. R. 1973. Changes in understory vegetation and fine root quantity following thinning of 30-year *Pinus radiata* in central North Island, New Zealand. J. Appl. Ecol. 10:13–21.

Percent cover of understory species in thinned and unthinned *Pinus radiata* stands is shown tabularly, while dry weights of the understory fine roots for the two treatments are graphically illustrated.

528. POTVIN, FRANCOIS, and JEAN HUOT. 1971. Deer browse production in small cutovers in southern Quebec. Wildl. Soc. Bull. 7:247–252.

The number of twigs and biomass of browse available to deer in each of the first 6 years after clearcutting hardwoods (mostly *Acer rubrum*) in mixed forests are summarized in tabulated form.

529. PRATCHETT, DAVID. 1978. Effects of bush clearing on grasslands in Botswana. *In* Proc. First Int. Rangeland Cong. p. 667–670. Denver, Colo.

Dry matter production and botanical composition with and without bush clearing are given.

530. PRATT, D. J., and J. KNIGHT. 1971. Brush-control studies in the drier areas of Kenya vs. effects of controlled burning and grazing management of *Tarchonanthus/Acacia* thicket. J. Appl. Ecol. 8:217–237.

Four study sites in the Rift Valley were burned differently: unburned, burned once, burned three times without previous slashing, and burned three times following slashing. Herbage production for the four sites is presented in tabulated form.

531. PRINGLE, W. L., C. R. ELLIOTT, and J. L. DOBB. 1973. Aspen regrowth in pastures of the Peace River region. J. Range Manage. 26:260–265.

Four consecutive years of forage yields following various tillage methods of *Populus tremuloides* sprout control in northern Canada are given (table).

532. PURDIE, R. W. 1977. Early stages of regeneration after burning in dry sclerophyll vegetation. I. Regeneration of the understory by vegetative means. Aust. J. Bot. 25:21–34.

Density of understory vegetation is given in tabulated form for control stands and for *Eucalyptus* stands thinned by fire in Australia.

533. SCOTTER, GEORGE W. 1975. Effect of picloram on cinquefoil and forage production at the Ya-Ha-Tinda Ranch, Alberta. J. Range Manage. 28:132–138.

Herbage production with and without the presence of *Potentilla fruticosa* is given in tabulated form.

534. SKOVLIN, JON M., and D. LEROY WILLIAMSON. 1978. Bush control and associated tse-tse fly problems of rangeland development on the coastal plain of East Africa. *In* Proc. First Int. Rangeland Cong. p. 581–583. Denver, Colo.

Grass, bush, and composition data are presented in graphic form. Overstory species include *Acacia zanzibarica* and *Hypaene thebaica*.

535. STRANG, R. M. 1974. Some manmade changes in successional trends on the Rhodesian highveld. J. Appl. Ecol. 11:249–263.

The effects of clearcutting, burning, and grazing on the overstory (*Brachystegia spiciformis/Julbernardia globiflora*) and understory vegetation in northeastern Rhodesia were studied. Mean relative densities of grasses on burned, grazed, and protected sites are discussed (tables).

536. TEFLER, E. S. 1972. Understory biomass in five forest types in southwestern Nova Scotia. Can. J. Bot. 50:1263–1267.

Herbaceous and shrubby biomass is presented in relation to biomass and basal area of different forest types. Information is presented in tabulated and graphic form for stands dominated mainly by *Picea, Abies, Acer, Populus*, and *Quercus*.

537. VAN NIEKERK, J. P., F. V. BESTER, and H. P. LOMARD. 1978. Control of bush encroachment by aerial herbicide spraying. *In* Proc. First Int. Rangeland Cong. p. 659–663. Denver, Colo.

From South Africa, grass production with and without chemical control of mixed bush overstories is given in tabulated form.

538. VEBLEN, T. T., D. H. ASHTON, F. M. SCHLEGEL, and A. T. VEBLEN. 1977. Distribution and dominance of species in the understory of a mixed evergreen-deciduous *Nothofagus* forest in southcentral Chile. J. Ecol. 65:815–830.

Frequency and cover of understory species are given for several forest types.

# APPENDIX

## AUTHOR INDEX

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This annotated bibliography is provided as a working tool for natural resource specialists and land-use planners attempting to (1) describe understory production, density, or composition associated with specific overstories; or (2) changes in understory characteristics resulting from conversion or modification of specific overstories.

KEYWORDS: bibliography, annotated, understory, overstory, relationships

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**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-137

December 1982

# Aerial Application of Douglas-fir Beetle Antiaggregative Pheromone: Equipment and Evaluation

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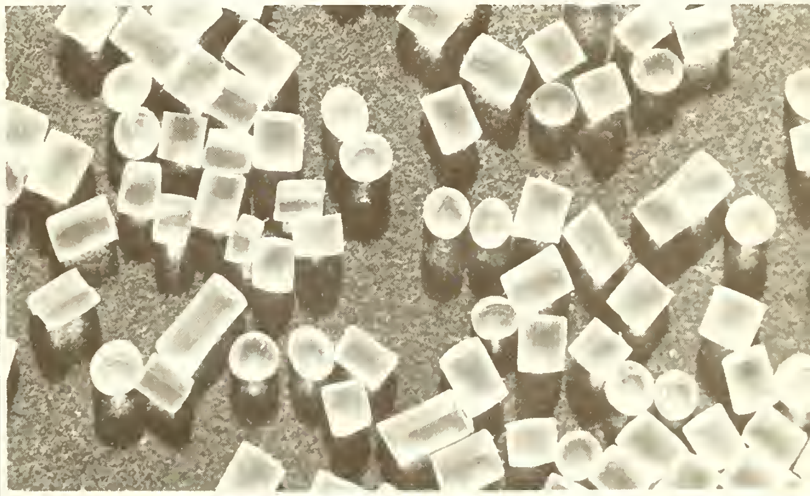

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Persons assisting in various airport tests in Montana, Idaho, and Oregon included: Anthony E. Jasumbach, David R. Bridgewater, Dennis R. Hamel, Phil Blair, and Richard L. Dudley, USDA Forest Service, and Paul E. Joseph, Oregon Department of Forestry. Others who aided in the field tests involving aerial application of granules to plots were: Nancy S. Mahaffie and Russell W. Clausen, University of Idaho, and Kenneth L. Ecton and Ellie H. Hoffman, USDA Forest Service. The conical traps were designed and constructed by Jack W. Hamilton, University of Idaho, Moscow, Idaho.

The manuscript was strengthened by the critical reviews of Dr. R. Ladd Livingston, Idaho Department of Lands; and William M. Ciesla and Mark D. McGregor, USDA Forest Service.


## RESEARCH SUMMARY


The Douglas-fir beetle antiaggregative pheromone, MCH (3-methyl-2-cyclohexen-1-one), has been shown to prevent to a high degree infestation of susceptible felled trees. This publication describes technology for application and evaluation of a granular controlled-release formulation containing 2 percent MCH. Included is a chronological discussion of developmental steps leading to modification and testing of a 40-$ft^3$ (1.13-$m^3$) bucket-type Simplex model 6400 aerial applicator for use in applying variable-size granules by helicopter at a recommended rate of approximately 4 lb/acre (4.48 kg/ha). Rate of application was measured on plots by conical traps. Methods of bioassaying MCH treatment, involving counts of attack sites (frass piles), bark samples, and measuring tree mortality, are discussed.



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United States
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# Aerial Application of Douglas-fir Beetle Antiaggregative Pheromone: Equipment and Evaluation

**Malcolm M. Furniss, George P. Markin, and Victor J. Hager**

## INTRODUCTION

The Douglas-fir beetle (DFB), *Dendroctonus pseudotsugae* Hopkins, is an important bark beetle in Douglas-fir forests of western North America (Furniss and Orr 1978). It often kills mature, dense groups of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, after its population increases in windfelled or otherwise susceptible trees. Preventive measures include maintaining stands below 80 percent of normal stocking and salvaging damaged trees. When windstorms fall trees in inaccessible locations, however, an alternative action is needed. For example, the antiaggregative pheromone, MCH, might be applied to deny beetles susceptible windfelled trees in which to breed, thereby maintaining the population status quo (Furniss and others 1981). Thus, the population is held in check by diverting beetles from susceptible windfelled trees to a more hostile environment, including live trees that have greater resistance than do felled trees. How to do so is the subject of this publication. Included is a chronological account of steps taken to modify and test the applicator, and suggestions for evaluating treatment.

Discovery of the attractant pheromone complex of *Ips paraconfusus* Lanier (Wood and others 1967) opened up a field of study that has resulted in identifying pheromones of many scolytids (Borden 1974, 1977). Among these are the DFB antiaggregative pheromone, 3-methyl-2-cyclohexen-1-one (MCH) (Kinzer and others 1971). The natural function of MCH is to reduce intraspecific competition by terminating attraction after a generally sufficient attack density has been achieved to overcome a tree's defenses (Rudinsky and Ryker 1976). Whether MCH masks the attractive pheromones frontalin (Pitman and Vité1970) and seudenol (Pitman and others 1974), which are synergized by $\alpha$-pinene (Furniss and Schmitz 1971), or whether MCH repels beetles, is uncertain.

Evaporation of MCH from glass vials in the vicinity of recently felled Douglas-fir reduced subsequent DFB attack densities up to 96 percent compared to untreated trees (Furniss and others 1974). A granular controlled-release formulation (U.S. Patent #4,170,631) containing 2 percent MCH proved to be equally effective when broadcast by hand around felled trees (Furniss and others 1977). The rod-shaped granules (fig. 1) vary severalfold in mass, and the technology for aerially applying small amounts, e.g., 4 lb/acre (4.48 kg/ha) of such granules was not available. Therefore, we adapted a fertilizer applicator to this purpose by modifying its rate of output and electrical circuitry. Other information presented are: calibration data, swath width, flight specifications, and methods of evaluating application rate and effectiveness of treatment.

Figure 1.—MCH is evaporated slowly from rod-shaped inert granules.

# APPLICATION TECHNOLOGY

## Chronology of Testing and Problems Encountered

### SIMPLEX MODEL 1600 SEEDER

In 1976 we began testing and developing technology needed to apply the granular controlled-release formulation of MCH at a rate of approximately 4 lb/acre (4.48 kg/ha) containing 2 percent actual MCH. Initially we tested a series 1600 Simplex[1] seeder on a Hiller 12E helicopter (fig. 2). A feeder mechanism was located beneath each hopper on either side of the helicopter. Each feeder consisted of a sliding gate to regulate the amount of granules released from its hopper, and an electric motor-driven rotary cylinder, fins on which moved granules until they dropped into a 3-in (7.6-cm) diameter, 8-ft (2.4-m) long tube. Granules were moved through the tube by an airstream of approximately 60 mi/h (96 km/h) provided by a hydraulically powered blower.

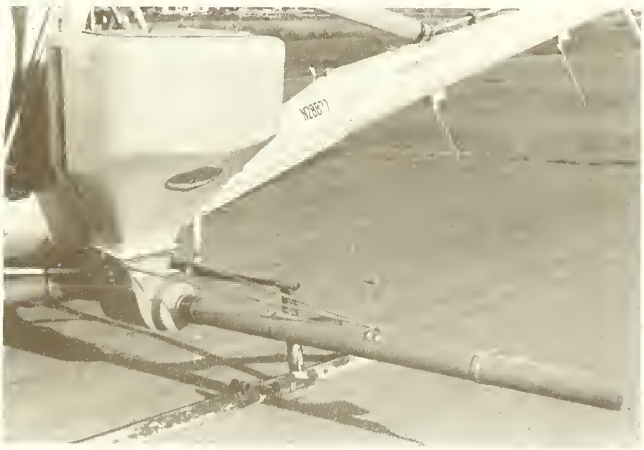


Figure 2.—Simplex seeder mounted on a Hiller 12E helicopter was used in early tests but the granules jammed the feeder mechanism.

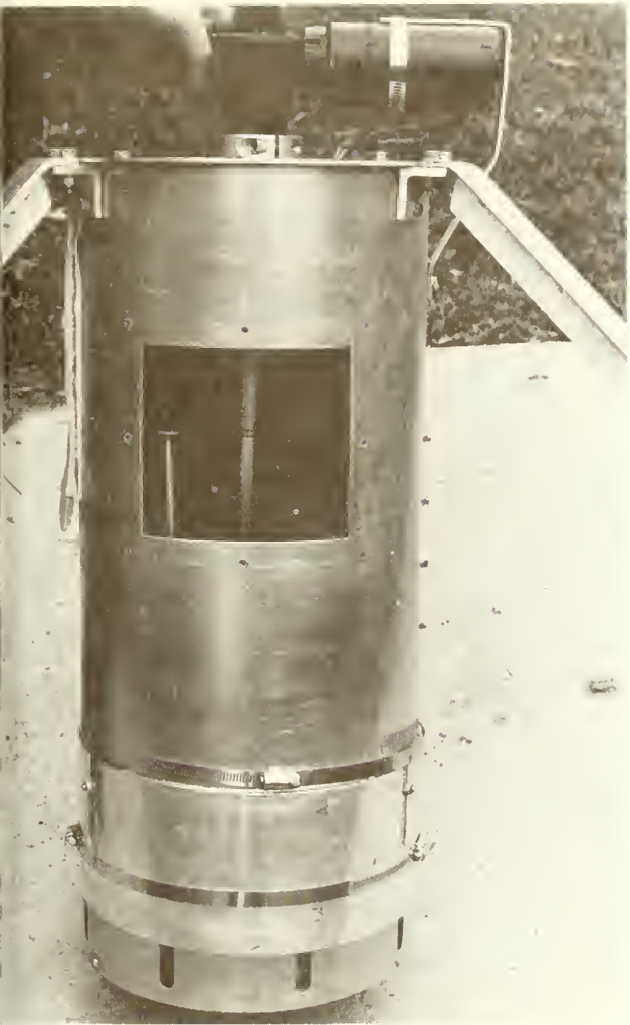
The seeder proved to be unsatisfactory. The incredibly tough polyamide dimer acid granules lodged between th rotor fins and the housing, jamming the feed mechanism overloading the motor circuit, and causing mechanical problems such as slippage of a drive wheel and piling of granules in the air tube and consequent uneven flow rate The seeder was tested on six flights prescribed at 45 mi/ (72.4 km/h) and 50-ft (15.2-m) elevation. The overall swath width varied from 80 ft (24.4 m) to 100 ft (30.5 m), probabl due to inadvertent differences in aircraft height and variable low-velocity lateral wind.

### SIMPLEX MODEL 3700 APPLICATOR

After consultation with representatives of Simplex Corporation, Portland, Oreg., we selected a model 3700, bucket-type applicator (fig. 3) for modification and testir The applicator was designed for applying fertilizer pelle at high rates, up to 200 lb/acre (224 kg/ha). It consisted o $40\text{-ft}^3$ (1.13-$m^3$) fiberglass bucket with an internal mechanism (fig. 4) for metering outflow of granules and an externally mounted 10 hp gasoline motor that drove a ho zontal spinning disc at the bottom of the bucket to disperse granules. The internal mechanism consisted of a central column (can) on top of which was a reversing electric motor that turned a screw shaft to open or close an internal, cylinder-shaped gate at the bottom of the ca The continuous opening created when the cylinder gate was raised is satisfactory for high rates of fertilizer app cation but not for the low rate required for formulated MCH.


Figure 3.—Simplex model 3700 applicator had a weakly supported internal mechanism (A) that resulted in misalinement and jamming of the gate mechanism by granules.

[1]Simplex Manufacturing Co., 5224 NE 42d Avenue, Portland, OR 97218.



igure 4.—Internal mechanism removed
om model 3700 applicator to show slotted
ınd and sliding collar at bottom.

The applicator was modified to reduce output of gran-
es by installing a slotted aluminum band inside an
djustable aluminum collar (fig. 4). Eight vertical slots,
5 in (1.27 cm) by 4 in (10.2 cm), were cut equal distances
part in the aluminum band. The collar was positioned to
ovide a desired slot opening and then held fast to the
otted band by a hose clamp.

The modified model 3700 applicator was calibrated on
e ground to deliver approximately 18 lb/min (8.2 kg/min)
granules with the collar set for a slot opening of 0.4 in
cm). That rate was calculated to provide 4 lb/acre
.48 kg/ha) based on a 50-ft (15.2-m) working swath, at
5 mi/h (72.4 km/h) and 50-ft (15.2-m) height.

The applicator was flown on a Hiller 12E helicopter over
nical traps set at 10-ft (3-m) intervals across the direc-
on of flight (described later under evaluation) at 45 mi/h
2.4 km/h) and 50-ft (15.2-m) elevation to determine swath
idth and uniformity of application. Eight swaths
eraged 106 ft (32.3 m) wide (R = 80 − 120 ft, 24.4 − 36.6 m). Because of the bell-shaped distribution of granules of a single application, a working swath width of 50 ft (15.2 m) was selected to provide overlap needed to obtain the desired average application rate (see Akesson and Yates 1974). When the granules from eight swaths were plotted with the flight lines 50 ft (15.2 m) apart, the average rate of application was 4.6 lb/acre (5.2 kg/ha) ± 20 percent. This rate was 15 percent higher than the recommended rate but could be adjusted either by increasing the aircraft speed, or reducing the slot openings.

In April 1979 the Simplex model 3700 applicator was used to apply granules containing MCH to forested plots on which trees were felled to simulate windthrow (Furniss and others 1981). Several problems developed with the applicator, as discussed subsequently, that contributed to varying rates of application. Even so, treatment rates averaging 1.58 to 10.98 lb/acre (1.41 to 9.80 kg/ha), measured on plots, reduced DFB attack density from 92 to 97 percent, indicating that an average rate of approximately 4 lb/acre (4.48 kg/ha) would be satisfactory.

The problems with the applicator were: (1) slot openings were difficult to set and required emptying the bucket and climbing inside, (2) catching and weighing granules during calibration of the applicator was inconvenient, (3) gate position could not be positively determined while in flight, (4) various internal mechanical and electrical problems occurred. Solutions to those problems were found by adapting an improved applicator (model 6400) as explained in the following section.

## MODIFICATION OF SIMPLEX 6400 APPLICATOR

The model 6400 applicator differed from the earlier 3700 model by having better support (fig. 5, 6) for the can that housed the gate mechanism. The supports stabilized the can, preventing misalignment of the gate that occurred with the model 3700 and avoided binding of the gate's movement by the nearly indestructible granules that lodged wherever misalignment caused a gap. We still found it necessary to modify some components, however, as discussed hereafter.

Due to the three vertical braces along the outer surface of the can, a single slotted-aluminum band could not be fitted around the can to restrict output. Instead, we installed three discontinuous stationary bands (fig. 5), each having three slots measuring 0.44 in (1.11 cm) wide by 4 in (10 cm) long. Outside each slotted band, we fitted a concentric sliding plate attached to a threaded, vertical, 0.25-in (6.4-mm) diameter control rod with an inscribed reference scale opposite its top end (fig. 6). The control rods enabled setting each plate for a precise slot opening without emptying or entering the bucket. Two lock nuts kept each plate from moving, once adjusted. Each plate and its slotted band were custom fitted to prevent gaps where granules might lodge.

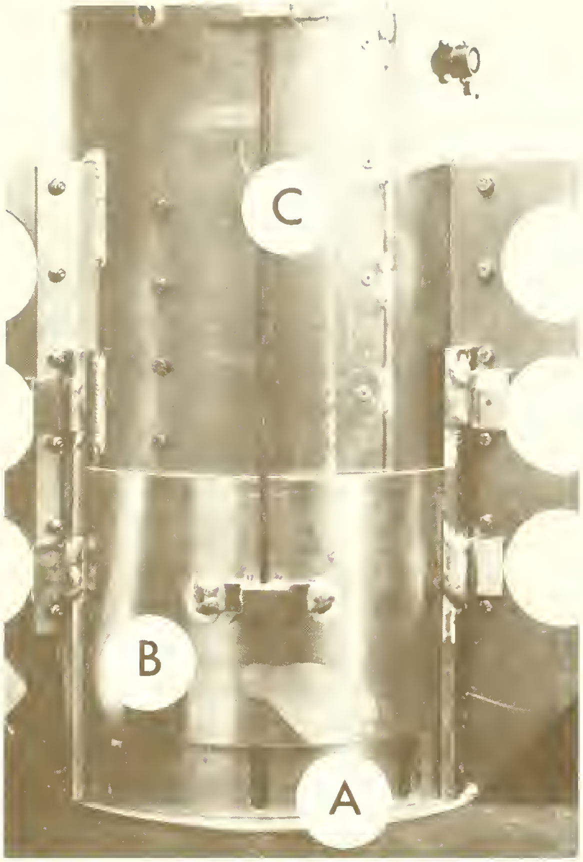



Figure 5.—Internal mechanism of model 6400 applicator showing slotted band (A) and sliding gate (B) installed between perforated side supports. The gate is raised and lowered by a threaded rod (C).

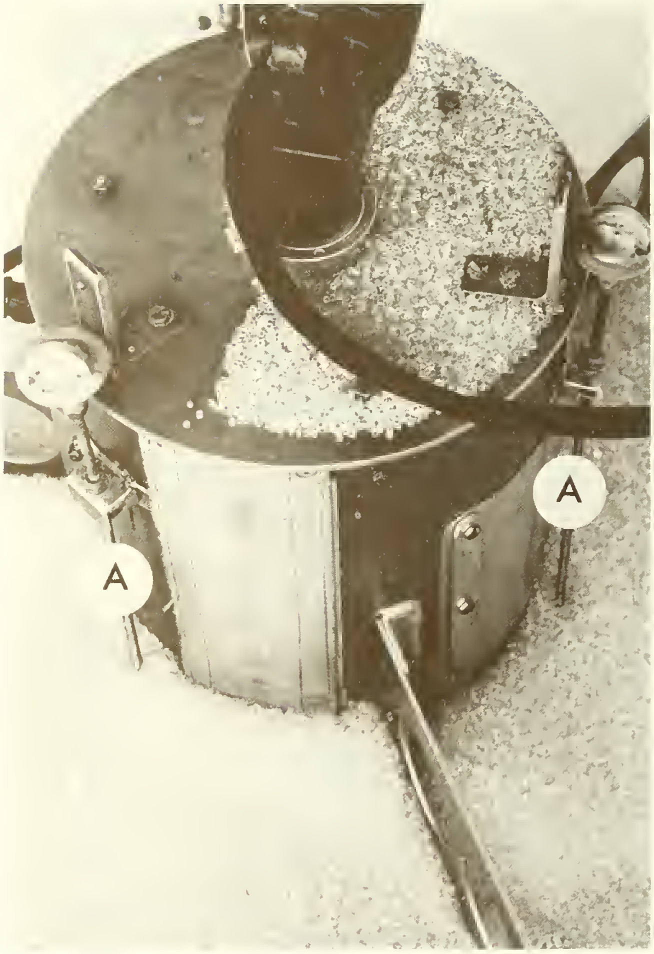



Figure 6.—Details of top of internal mechanism of model 6400 applicator loaded with granules. The opening of each gate can be conveniently and accurately regulated by turning the threaded control rods (A).

To conveniently catch granules during preflight calibration of slot openings, we built and installed a catcher (fig. 7) of 24-gage galvanized sheet iron, with a dump spout at the bottom. The catcher was installed by raising the applicator on blocks. Because the spinning disc caused granules to bounce and escape through the narrow top opening, we installed a spiral cleat inside the catcher to deflect granules downward. Also, the opening at the top of the catcher was reduced to a minimum with nylon netting and Velcro fasteners. With the catcher in place, we ran 30-second replicates at intervals of about 1 minute.

A red light was attached to an external support on the applicator to signal to observers on the ground when the gate was open. The light was a single-contact automotive-type directional light having an Auto Lamp No. 567 bulb (24 v, 32 candlepower). The light was activated by a microswitch mounted inside the bottom of the can.

We found it desirable to install a positive up (on) and positive down (off) toggle switch on the pilot's control stick to indicate that the gate was open or closed. A spring-loaded switch would require the pilot to maintain the switch in the on or off position until the gate had closed or opened. The pilot cannot monitor the gate position, however, and other duties while flying make it desirable to free the pilot by using a positive on or off switch.

The housing of the switch that we built was sufficiently large that its weight changed handling characteristics of the control stick. Thus, care should be taken to keep its weight minimal and to have the pilot flight test it before the applicator is attached. A fuse should be incorporated into the switch housing for safety.

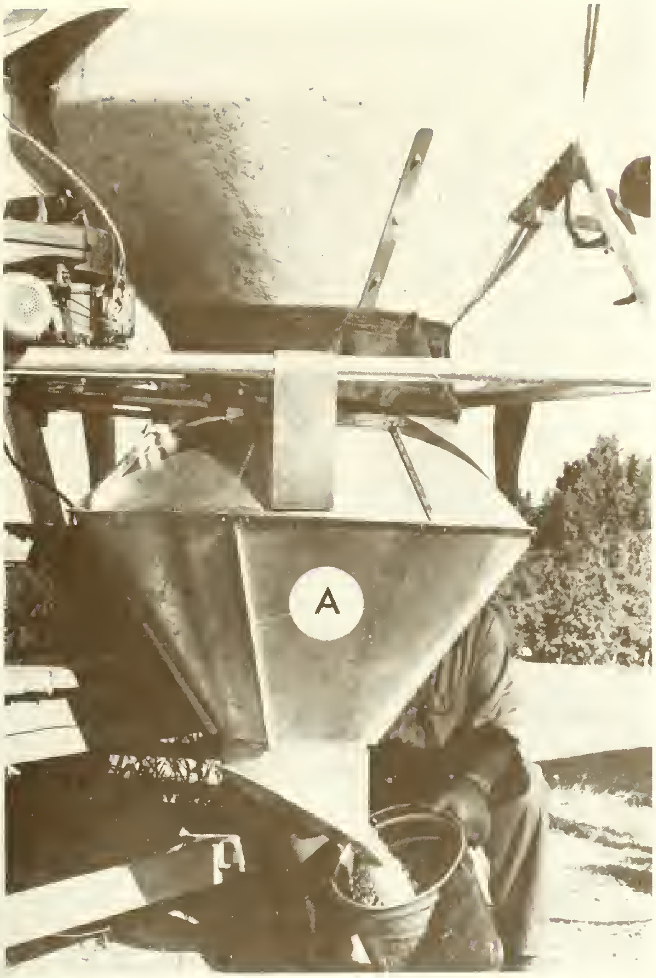


Figure 7.—Catcher (A) installed beneath applicator to catch granules during static calibration tests.

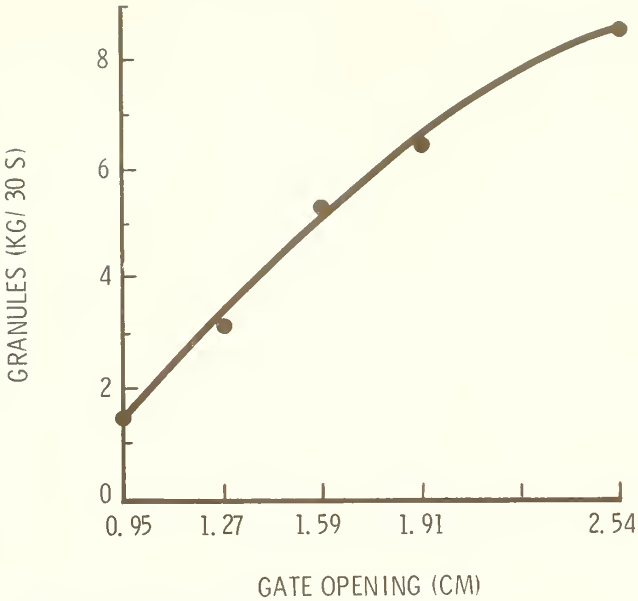



Figure 8.—Relationship between slot opening and output of granules.

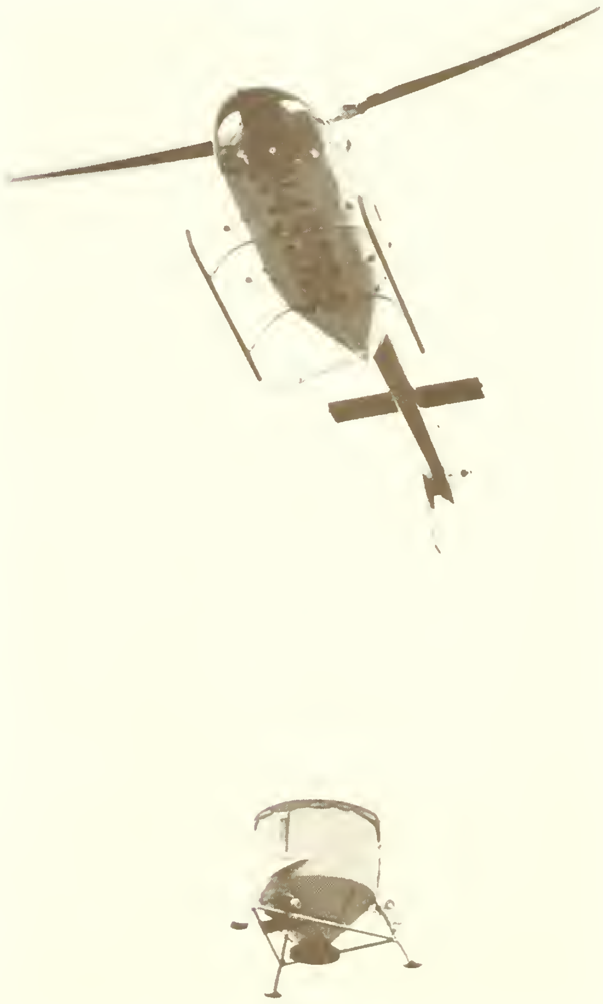


Figure 9.—The modified model 6400 applicator functioned reliably in aerial tests with a Bell 206 helicopter.

## CALIBRATION OF THE MODIFIED MODEL 6400 APPLICATOR

With the applicator on blocks and the catcher in place, we ran 30-second replicates to determine relationship of slot openings and output of granules. A slot opening of 0.63-in (1.6-cm) height (2.5 in$^2$ [16 cm$^2$] total for the nine slots) resulted in an average output of 11.7 lb (5.32 kg)/30 s ($n = 54$, $SD = 0.71$ lb $= 0.32$ kg). Using the relationship shown in figure 8, other slot openings can be selected for other application rates.

After calibration, we flight-tested the modified applicator (fig. 9) with 0.63-in (1.6-cm) slot openings to determine rate of application of two overlapping swaths 50 ft (15.2 m) apart. The applicator was tested with a Bell 206 helicopter on September 10, 1980, at 2,950-ft (900-m) elevation in Smith Meadow 3 mi (5 km) north of Deary, Idaho. Eleven conical traps (described under Evaluation of Treatment) were set out 10 ft (3 m) apart on five lines at right angles to the direction of flight. Lines were 200 ft (61 m) apart. The pilot was requested to fly at 50 mi/h (80 km/h) with the bucket 50 ft (15.2 m) above ground. Sixty flights, in pairs of two flights 50 ft (15.2 m) apart, were made. The applicator functioned without any problem and the indicator light allowed us to immediately detect one flight on which the pilot failed to turn on the switch. Results are shown in table 1.[2]

Table 1.—Application rates at 200-ft intervals for overlapping swaths 50 ft apart

| Interval | Number of traps observed | Lb/acre | (kg/ha) | Coefficient of variation |
|---|---|---|---|---|
| 1 | 180 | 3.29 | (3.69) | 63 |
| 2 | 180 | 3.75 | (4.20) | 51 |
| 3 | 180 | 4.12 | (4.62) | 50 |
| 4 | 180 | 4.18 | (4.69) | 51 |
| 5 | 180 | 4.31 | (4.83) | 53 |
| Average | | 3.93 | (4.40) | 55 |

The variation within lines is mainly due to the ballistics of nonuniform size granules. Similar variation did not lessen the effectiveness of MCH odor in a recent test (Furniss and others 1981). We did, however, look for other sources of variation in application rate between lines.

We monitored the speed of the helicopter with a stopwatch and found that it traversed 1,090 ft (332 m) in an average of 15.4 s (R = 13.5 to 17.8), which was equal to 48 mi/h (77.7 km/h) (R = 43 to 55 mi/h [67 to 88.5 km/h]). Thus, some of the variation was attributed to deviation from the specified aircraft speed.

We also measured the height of the bucket above ground at lines 1 and 5. The average height at line 1 was 63 ft (19.2 m); at line 5 it was 52 ft (15.9 m). The probable reason for the higher height at line 1 was the presence of a forested hill that may have caused the pilot to approach higher from that end. The probable effect of higher elevation would be less dense dispersal of the granules, which is indicated in table 1.

## EVALUATION OF TREATMENT

Rate of application should be determined by sampling granules that fall on the ground. A suitable way of doing so is with a funnel trap (fig. 10) modified from that described by Stringer and others (1973).

The trap has a 3-ft$^2$ (0.28-m$^2$) (23.5-in, 59.7-cm diameter) top opening and a 0.63-in (1.6-cm) diameter bottom opening. The funnel is 20 in (0.51 m) deep and is made of a 24-gage galvanized sheet iron with a spotwelded seam. A flaring tool is used to form a uniform bottom opening and to reshape holes that become deformed during transportation to the field. A 2-in (5.1-cm) length of 3/4-in (2-cm) inside diameter PVC tube with a window screen bottom for draining rainwater is attached to the funnel outlet with a wire clip to collect granules (fig. 10B). A stand made of 1/4-in (0.64-cm) diameter iron is thrust in the ground to hold the funnel upright. Tape can be applied to assure that the funnel is held upright in the stand.

For operational use it may be more practical to count rather than weigh, granules caught by traps. The equivalent rate of application in pounds per acre (kilograms per hectare) of the number of granules caught per 3-ft$^2$ (0.28-m$^2$) cone trap can be calculated by multiplying the number of granules caught per trap times a conversion factor. Based on an average weight of 12.90 mg per granule in our 1980 calibration test, the factors were 0.41294 (= lb/acre) and 0.4623 (= kg/ha). New factors may be derived by the proportion of any different average weight per granule (X) times our factor; e.g., (X/12.90) (0.41294).

An alternative method is to remove the tubes containing granules, apply a cork stopper, and place them in a carrying case for eventual weighing. The weight of granules (in grams) per trap can be converted to pounds per acre by multiplying by 32.01 or to kilograms per hectare by multiplying by 35.88.

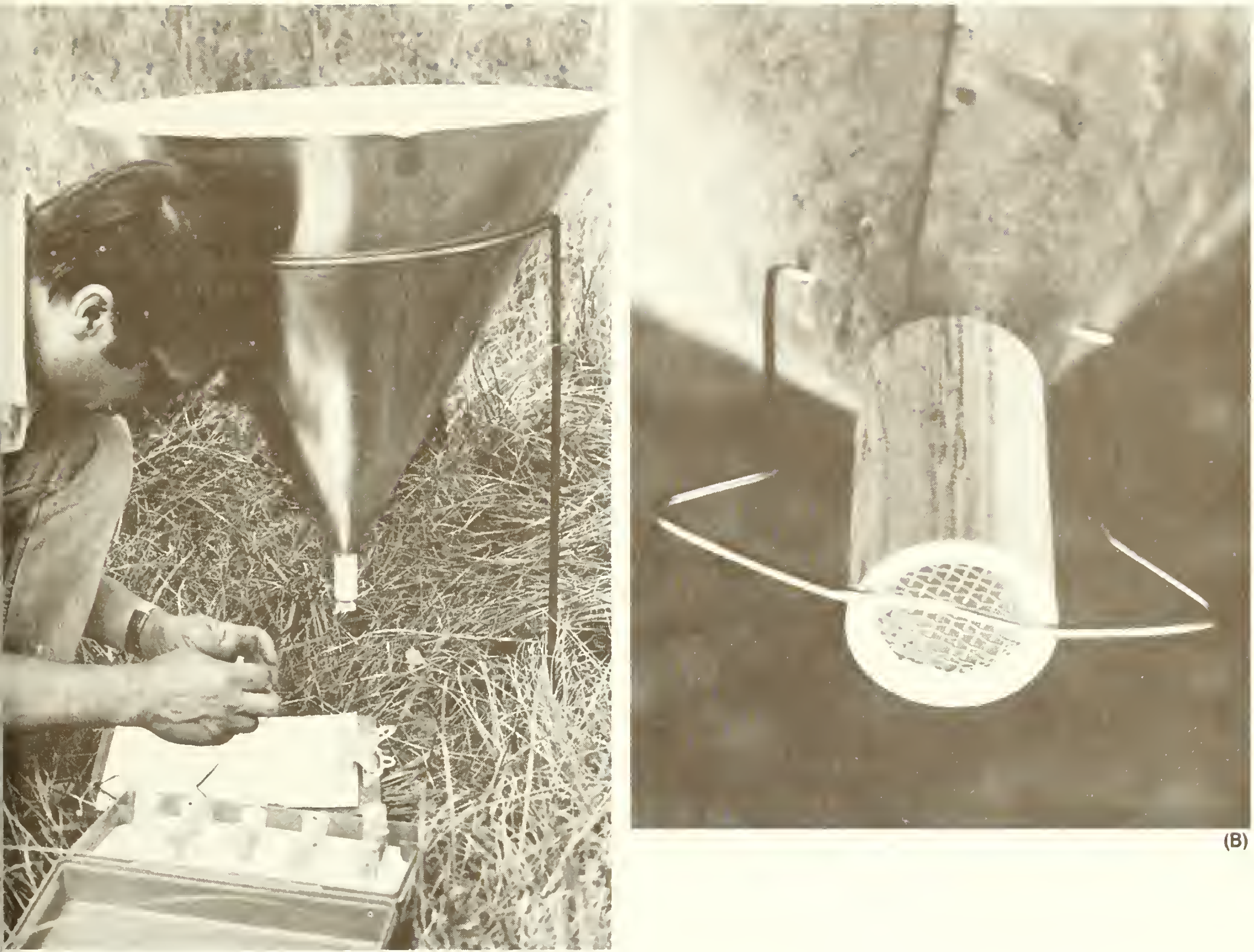
Cones should be placed across flight lines but clustered in the vicinity of windthrow, which may be unevenly distributed. Sampling in the vicinity of windthrow will take advantage of more open overstory, and the density of application there may be more important in reducing subsequent DFB infestation.

The number of cone traps set out will be limited by their bulk, work force available, and cost. We used 7.43 traps per hectare for study purposes (Furniss and others 1981).

### Bioassay of Treatment

DFB infestation in windthrown trees can be evaluated by (1) counting piles of "frass" (mostly expelled phloem fragments) on bark, (2) counting and measuring egg galleries on bark samples, and (3) counting progeny on bark samples. The three methods are listed in increasing order of work and time involved.

[2]Based on granules caught by traps between the flight lines, in order to obtain overlap of two flights.




gure 10.—(A) Conical trap used to catch anules during aerial test of applicator. (B) ɛtail of removable screen-bottom tube stalled at outlet of trap.

## ƎASS COUNTS

Frass is conspicuous in early June while it is bright ange and has not been bleached by sun or diminished ' rain or wind. Although attacks may be hidden from ew on the underside, counts of visible frass can ovide a preliminary evaluation of treatment and dicate whether or not bark samples may be needed. A ɛcision on whether to proceed with obtaining bark ımple data is influenced by cost, which was 50 times eater than for counting frass in a recent test (Furniss ıd others 1981). If bark sampling is deemed necessary, can be expedited by stratifying trees by densities of eir frass counts in order to weight the samples to represent the population. Those trees having few or no visible attacks need not be sampled.

## BARK SAMPLES

Factors that influence the location of sampling for DFB are: DFB attacks in felled trees are usually more dense on the underside (Furniss 1962), especially if the upper side is sun-exposed, and a less important bark beetle, *Pseudohylesinus nebulosus* Lec., may predominate in portions of the trunk smaller than 12 in (30 cm) in diameter.

For statistical efficiency, the area of the ultimate sampling unit should vary inversely with density of the variable sampled. Because DFB egg galleries (or attacking parent beetles) are less dense in windthrow than the number of progeny produced, we commonly use a 12- by 12-in (30- by 30-cm) sample (fig. 11) for measuring attack density and a subsample of 6 by 6 in (15 by 15 cm) for progeny.

A practical procedure is to take three bark samples on the lower, shaded side, spaced equidistant below a 12-in (30-cm) diameter, for example one-fourth, one-half, and three-fourths of the distance between the root crown and the 12-in (30-cm) diameter. The number of such samples required for estimating the mean density of attack or progeny varies with the level of probability and accuracy desired and with the particular trees and population level. A good method is to sample several representative trees and solve for the needed number by the formula: $n = (CV_x/0.20)^2$ as suggested by Kish (1965). Of course, other relative coefficients of variation of the mean can be substituted for 0.20 in the formula.

## EVALUATION OF TREE MORTALITY

Measurement of the reduction of tree mortality due to treatment of windthrow with MCH is difficult. The sources of beetles that infest live trees can only be inferred. The beetle is a good flyer, having been observed to fly continuously up to 6 h at an average of 2.5 mi/h (4 km/h) on flight mills like those described by Smith and Furniss (1966). More than one flight may occur. But many beetles probably respond to environmental stimuli, including odors of trees being infested, if present, within a few miles of flight. Once a female beetle arrests her flight and begins invading a tree, a powerful attraction is created by the interaction of her aggregating pheromones, frontalin and seudenol (Pitman and Vité 1970; Pitman and others 1974) and resin odor (Furniss and Schmitz 1971). The ensuing aggregation of beetles typically results in a discrete group of trees being infested. Such trees become discolored and appear red by June of the following year, and can be readily detected on aerial photos taken then (McGregor and others 1975).

Evaluation of tree mortality in stands surrounding MCH treatment should begin by taking aerial photos during July of the year of treatment to obtain a base for comparison with later measurements. DFB progeny will not emerge until the year following MCH application. Trees that they infest will not have entirely discolored until a year later. Thus, final evaluation of tree mortality after MCH treatment is not possible until 2 years after treatment.

Groups of discolored trees killed by DFB are easily identified on true color stereo aerial photos of 1:15840 scale or larger. We recommend obtaining such aerial photos of stands in a 3-mi (4.8-km) radius around the MCH-treated area containing windthrow. With such photos, crews can readily locate and measure groups of DFB-killed trees. Should the mortality be so extensive as to require it, discolored trees can be counted on the photos and those counts adjusted by measuring sample groups on the ground (McGregor and others 1975).

**Figure 11.—Bark sample used to measure Douglas-fir beetle infestation in windthrown trees.**

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The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

Furniss, Malcolm.; Markin, George P.; Hager, Victor J. Aerial application of Douglas-fir beetle antiaggregative pheromone: equipment and evaluation. Gen. Tech. Rep. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 9 p.

A 40-$ft^3$ (1.13-$m^3$) bucket-type aerial applicator was modified and tested for applying granules containing Douglas-fir beetle antiaggregative pheromone (MCH). Specifications are given for modifying the applicator and applying the formulation at a recommended rate of approximately 4 lb/acre (4.48 kg/ha) for preventing infestation and consequent population release in windthrown trees. Included are methods for evaluating rate of application using conical traps, and determining treatment effectiveness by use of frass counts, bark samples, and measurement of tree mortality.

KEYWORDS: Aerial application, methylcyclohexenone, MCH, pheromone, controlled-release formulation, Douglas-fir beetle, bark beetle control

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# Methods For Evaluating Stream, Riparian, and Biotic Conditions

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## RESEARCH SUMMARY

Most stream habitat evaluation techniques currently in use today have not been tested to determine their validity in describing conditions and have been designed to optimize time rather than accuracy. The purpose of this report is to further standardize the way physical and biological attributes are measured and quantified and to shed light on the strengths and weaknesses of those attributes. This report discusses some of the environmental parameters that best measure and describe conditions existing in aquatic ecosystems. The precision and an estimation of the accuracy that can be expected when measuring many of these conditions are given.

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# CONTENTS

# Methods For Evaluating Stream, Riparian, and Biotic Conditions

**William S. Platts**
**Walter F. Megahan**
**G. Wayne Minshall**

## NTRODUCTION

### 3ackground

The past decade has seen an increase in the number of studies valuating the status and potential of streams as habitats for quatic organisms. Stream inventories, monitoring, habitat esearch studies, assessments, channel and flow condition evaluaons, and classification are used to evaluate this potential. The uccess or failure of these stream studies depends on the suitabili-/, comprehensiveness, precision, and accuracy of measurements sed to obtain the data upon which final interpretations are based. 'hese interpretations have been used by planners and decision-nakers on the assumption that they were derived from neasurements that truly described stream habitat conditions and ne resulting biotic community.

Within the past decade measurements of stream habitat condiions, such as velocity, depth, and cover, have been incorporated nto models designed to indicate fish standing crops and to assist n evaluating impacts from land management activities. Binns 1979) developed a Habitat Quality Index to predict trout standing rops in Wyoming streams. The USDI Fish and Wildlife Service Cooperative In-stream Flow Group) uses a cluster of aquatic abitat descriptors in a predictive model to quantify the effects of hange in streamflow on fish survival. Their Aquatic Habitat ;valuation Team also has developed an Aquatic Habitat Evaluation 'rocedures model (HEP) and Habitat Suitability Index model HSI) for obtaining data and interpretation for use in decisionmakng. Wesche (1974) developed a cover rating model that is used n Wyoming streams to determine aquatic habitat conditions and ish standing crops. Cooper (1976) employed an aquatic habitat urvey model to measure stream channel conditions for information needed for land use planning. The success of these models lepends on whether the model fits the situation, whether the corect combination of habitat descriptors is selected, and how recisely and accurately the habitat descriptors are measured.

### Problem

Difficulties arise in developing accurate, complete methodologies because of problems encountered in attempting to quantitatively determine the true state of an aquatic system (Platts 1976). In addition, aquatic specialitists commonly collect their data during the warmer months of the year (from June through September), when access, streamflow, and water quality are optimum for aquatic observation. Aquatic habitats and their biotic communities are seldom evaluated during periods of floods, annual high flows, extreme low flows, anchor ice buildup, ice flow scouring, debris jam breakup, or sudden toxic flushes. Because some important limiting factors, inside or outside the system, usually exert their effects during periods of no data collection, true existing states, or the changes of these states over time in the stream have rarely been determined. A valid understanding of the mix of environmental conditions that control the fishery, therefore, eludes us.

Platts (1974, 1976) demonstrated that while masses of multivariable environmental data can be gathered during these warmer months, complete and reliable information still is lacking. His study also demonstrated that additional descriptive variables, not yet discovered, are needed if adequate quantification of stream condition is to be gained. In today's methodologies (where the "state-of-the-art" lacks refinement and the form often is directed by expediency and low cost), the observed physical, biological, and chemical conditions and variations used to predict fishery condition and reaction often are of low value for providing valid interpretations. These deficiencies must be taken into account by the user when designing procedures, collecting data, and making interpretations.

Most techniques used today to evaluate stream habitat are untested and were designed to optimize time rather than accuracy. Problems can arise if the stream methodology used is not suitable for the environmental situation and if the accuracy of interpretations is not known. Poor resource management decisions can result.

## Purpose

The major purpose of this report is to help standardize the way that physical and biological attributes are measured and quantified and to shed light on the strengths and weaknesses of these attributes. Standardization of measurement techniques makes it possible to utilize information from area to area, compare study results, and evaluate information on a uniform basis. Only through constant refinement of present methods, incorporation of additional attributes, and standardization will we ever develop a practical means of obtaining information of use to resource managers. This report takes a step toward this goal and is presented in a format upon which future work can build and improve, thus continually upgrading the value and dependability of habitat and biomass assessment. With this improvement will come confidence in answering questions such as: (1) How much flow is needed in a specific stream for fish perpetuation? (2) How many cattle can be grazed in the riparian zone without excessive damage to the stream? (3) How much sediment can a stream take without losing productivity and will this timber sale exceed that amount? (4) Has the stream been altered from its natural condition? (5) Has the alteration depressed fish populations? (6) And, what needs to be done to rehabilitate the stream?

We hope to improve our methodology by providing an analysis of some of the attributes that are used in computer models or in methods to directly determine stream habitat and biotic conditions. The procedures identified in this report are intended for use by field personnel, such as biologists, hydrologists, aquatic specialists, watershed managers, entomologists, or others involved in providing information for resource management decisions. Our goal is to build a valid, objective, quantitative, repeatable procedure that will provide accurate evaluation of the stream and its biotic communities under any set of conditions. This report (1) presents standard techniques for measuring the aquatic, riparian, and biotic attributes, and (2) stresses the precision and accuracy that can be expected for each measurement. We acknowledge that this report is no panacea and that it provides no magic formula for answering all questions. Its purpose is to provide the field specialist with a method of building on and evaluating the methodology chosen to measure a particular aquatic habitat. The report is directed mainly toward ways of measuring the effects of land use practices, such as logging, road construction, livestock grazing, and mining. It does not address the hydrochemical environment or lower organisms, such as algae. Much refining and testing remains before a valid standard methodology will be available.

## Solution

Identification of limiting or enhancing environmental factors is essential to the solution of any biological resource problem. Our inability to measure these factors often keeps us from determining the true dominant limiting factors. For the present, we need to use the best approaches or methods available and define their accuracy and precision.

This report discusses some of the environmental parameters that best measure and describe conditions existing in aquatic ecosystems. These parameters were based on the following criteria:

1. They describe as accurately as possible the physical or biotic portion of the aquatic habitat for which they are designed;
2. They singly or in concert provide the user with insight into what controls biotic communities;
3. They are useful in diagnosing deficiencies in stream habitats; and
4. They avoid duplication and overlap.

# STUDY SITES

## Aquatic Habitat

Much of the methodology presented in this section was tested on 51 streams in Idaho, 2 in Utah, and 2 in Nevada. The Idaho testing was done in four major areas. One area included 38 tributaries of the South Fork Salmon River where the methods were tested over a 2-year period. The second area included six streams scattered within the Salmon River, the Middle Fork Salmon River, and the South Fork Salmon River drainages where the methods were tested over a 6-year period. The third area included four major chinook salmon (*Onchorhyncus tshawytscha* [Walbaum]) spawning areas in the South Fork Salmon River to be tested over a 15-year period. The fourth area included seven streams in the Middle Fork Payette River drainage to be tested over a 7-year period.

The Utah-Nevada streams were representative of those found in the Basin-Range physiographic province and the Idaho streams were representative of those found in the Rocky Mountain physiographic province (Bailey 1980). The test streams ranged in elevation above mean sea level from 4,500 to 7,500 ft (1 372 to 2 286 m).

A complete description of the study streams is given in Platts (1968), Platts (1974), Platts and Megahan (1975), Platts (1978), and Megahan and others (1980).

## Fisheries

The methods for analyzing fish populations are based on tests made over a 2-year period in 38 tributaries of the South Fork Salmon River where collections were obtained by the use of explosives and tests made over a 6-year period in five streams in the Salmon River, Middle Fork Salmon River, and South Fork Salmon River drainages in Idaho where electrofishing procedures were used. Two streams in Utah and two in Nevada were also studied for 2 years to test the reliability of electrofishing.

# SAMPLING DESIGN

Usually it is physically, and almost always financially, impossible to make a 100 percent inventory of a condition of concern in the riparian or stream environment. As a consequence, it is necessary to devise a sampling system to provide as accurate a measure of the attribute as possible with acceptable cost and effort. Sampling does not always cause a reduction in reliability just because fewer measurements are taken; good data properly collected on 10 percent of a population can often provide more reliable information than poor data collected on 100 percent of the population.

A population is defined as the set of all possible measurements of the attribute being measured. For example, a fishery biologist might be concerned about the effects of accelerated sedimentation on fry survival in a salmon spawning area. The spawning area covers the entire 50-ft (15.2-m) width of a channel and extends along that stream for 200 ft (60.96 m) providing a total area of 10,000 ft$^2$ (929 m$^2$). Assuming a 1-ft$^2$ (0.09-m$^2$) core sampler is available, the population consists of 10,000 individual cores. Obviously, it would be impossible to collect 10,000 cores to describe the population. Sampling a portion of the population provides a means of estimating population characteristics, such as its mean and variability, and of defining the reliability of the estimates.

The purpose of this section (and, to a large extent, the entire manual) is to stress that any sample is an estimate of the characteristics of the population and, as such, is subject to error.

Anyone using sampling must be aware of the possibility of error and account for it or describe it. When possible, we have provided some measure of the reliability of the measurements described in this manual, using actual data collected over a number of years in our study streams.

In some cases, only very basic procedures are provided here. If necessary, additional guidance is available in handbooks, standard statistical texts, and from statisticians.

## Bias, Accuracy, and Precision

Bias can be considered as any systematic error introduced into a sampling scheme. Bias often results from a lack of randomness in the selection of sample sites. Random selection simply means that every individual in the population has an equal chance of being selected. For example, bias could easily result if a stream surveyor were to sample stream depths by wading with hip boots in January — there would be a natural and understandable tendency to avoid deep sections where boots might be overtopped. In this case, the sample is not random because the greater depths were consciously, or perhaps unconsciously, avoided. Usually some mechanical system is used for site selection to avoid such bias. A table of random numbers or measurements from some arbitrary point is often used to accomplish this. Bias can also result from systematic errors in the measurement process. For example, the stream surveyor who measures water depths while leaning on the measurement rod to maintain balance could easily be introducing bias because the rod tends to sink into the bottom sediments. Investigators should do their best to avoid all known sources of bias in the site selection and measurement process.

Many kinds of errors, including unavoidable bias, exist to influence the accuracy of the data. Accuracy is the degree to which the measured value corresponds to the true value of the population. Unfortunately, the true population value, for example the population mean, is almost never known in natural systems. The best the investigator can do is to avoid bias and make the measurements as precise as possible. Precision can be defined as the repeatability of a series of measurements. Low precision is usually caused by poor or sloppy measurement techniques. Wide differfences between successive measurements or observers is a sure sign of low precision.

Target shooting provides an analogy for the terms "precision," "bias," and "accuracy." A wide grouping of hits all over the target indicates poor precision and poor accuracy. A close grouping indicates high precision, but not necessarily high accuracy. This apparent contradiction can occur when the group is not near the center of the target and is the direct result of bias. A very close group, randomly spaced at the center of the target, indicates unbiased, high precision, and high accuracy shooting. Unlike target shooting, it is almost always impossible to define accuracy in natural systems because the true population values are unknown.

## Population Parameters

A parameter is a value used to describe a population. Oftentimes, the mean of the population is the parameter of interest. Means may have limited utility, however, because they give no measure of the dispersion of the values in the population. Accordingly, a second parameter, such as the variance or standard deviation, is often used to estimate population dispersion.

The sample mean, $\bar{X}$, is expressed as:

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

where $X_i$ equals the individual sample values and n is the total number of samples.

The sample variance, $S^2$, is:

$$S^2 = \frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n-1}.$$

An alternative method for computing variance is:

$$S^2 = \frac{\sum_{i=1}^{n} (X_i)^2 - \frac{\left(\sum_{i=1}^{n} X_i\right)^2}{n}}{n-1}.$$

The standard deviation, S, is simply the square root of the variance.

One other value provides a dimensionless measure of dispersion; the coefficient of variation (C.V.) is expressed by the ratio of the standard deviation to the mean:

$$C.V. = \frac{S}{\bar{X}}.$$

Some streambed sediment data collected with a McNcil core sampler on the South Fork of the Salmon River during 1971 provide an example of the use of these equations. Twenty samples were collected in the Poverty chinook salmon spawning area in the South Fork Salmon River, Idaho, using a random sampling technique to represent the percentage by weight of the upper 12 inches (30.5 mm) of streambed sediments that are less than 0.25 inch (6.35 mm) in size. The data are listed as follows:

| Sample number | Percentage of sample less than 0.25 inch (6.35 mm) by weight |
|---|---|
| 1 | 44 |
| 2 | 16 |
| 3 | 29 |
| 4 | 40 |
| 5 | 31 |
| 6 | 51 |
| 7 | 22 |
| 8 | 22 |
| 9 | 35 |
| 10 | 42 |
| 11 | 41 |
| 12 | 15 |
| 13 | 21 |
| 14 | 37 |
| 15 | 39 |
| 16 | 27 |
| 17 | 37 |
| 18 | 27 |
| 19 | 26 |
| 20 | 45 |
| Total | 647 |

The estimated population parameters for this sample of 20 cores are calculated as follows:

$$\text{Mean} = \overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} = \frac{647}{20}$$

$$= 32.35 \text{ percent.}$$

$$\text{Variance} = S^2 \; \frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{n-1}$$

$$= \frac{1{,}986.55}{19} = 104.56 \text{ percent.}$$

$$\text{Alternately, } S^2 = \frac{\sum_{i=1}^{n} (X_i)^2 - \frac{(\sum_{i=1}^{n} X_i)^2}{n}}{n-1}$$

$$= \frac{22{,}917 - \frac{(647)^2}{20}}{19} = 104.56 \text{ percent.}$$

$$\text{Standard deviation} = S = \sqrt{S^2} = \sqrt{104.56} \text{ percent}$$

$$= 10.22 \text{ percent.}$$

$$\text{Coefficient variation} = C.V. = \frac{S}{\overline{X}} = \frac{10.22}{32.35}$$

$$= 0.36.$$

## Standard Error

The equation for standard deviation presented above provides an estimate of the amount of variation occurring within a population based on a single sample from the population. Because there is variation within the population, the means for successive samples taken from that population also will vary. A measure of the variability between the various sample means is the standard error of the mean. The standard error of the mean is analogous to the standard deviation in that it provides a measure of the variability of individual sample means, just as the standard deviation provides a measure of the variability of individual population values. The standard error of the mean is very useful because it makes it possible to estimate the reliability of the sample mean. The standard error of the mean, $S\bar{x}$, is evaluated using the sample variance and number of observations as:

$$S\bar{x} = \sqrt{\frac{S^2}{n}}.$$

## Confidence Limits

The reliability of a sample mean is expressed by the confidence limits for the sample. Sample means presented without some expression of their reliability are almost worthless. Freeze (1967) expresses it well:

> We have it on good authority that "you can fool all of the people some of the time." The oldest and simplest device for misleading folks is the barefaced lie. A method that is nearly as effective and far more subtle is to report a sample estimate without any indication of its reliability.

The confidence intervals (C.I.) for a sample mean are calculated by:[1]

C.I. = mean ± (t) (standard error).

The value t is taken from the Student's distribution (appendix 1). In the table, the column headed "d.f." refers to degrees of freedom and is based on sample size. The d.f. selected for use in the table is equal to n-1 for the sample. The column labeled "Probability" determines the kinds of odds the investigator is willing to accept. For example, a probability of 0.05 means that there is only a 5 percent chance that the true mean will fall outside the confidence limits.

For the Poverty spawning area data presented earlier, the standard error of the mean is:

$$S\bar{x} = \sqrt{\frac{S^2}{n}} = \sqrt{\frac{104.56}{20}} = 2.29 \text{ percent.}$$

And the confidence interval, using d.f. equal to 19 (n-1 or 20-1) at the 0.05 probability level, is:

$$C.I. = \bar{x} \pm (t)(S\bar{x}) = 32.35 \pm (2.093)(2.29)$$

$$= 27.56 \text{ to } 37.14 \text{ percent.}$$

[1]The use of the t statistic assumes that the sample data follow the normal (Gaussian) distribution. Usually, the distribution of data is close enough to the normal distribution that use of the t statistic is warranted. However, tests for normality should be applied if there is any question. An example is provided by percentages, such as those used in the example data set. Percentages may not be normally distributed if many of the sample values fall above 80 or below 20 percent. Data transformations may be useful for assuring normality of a data set. Tests for normality and the necessary data transformations needed to assure normality are presented in standard statistical texts. No normality tests were used for the example data because all values, with one exception, were greater than 20 percent.

For this data set, the probability is 0.05 (or a 1 in 20 chance) ıat the population mean is outside the range of from 27.56 to 7.14. The more common way to look at this confidence interval ; that there is a 95 percent chance that the population mean falls /ithin the range from 27.56 to 37.14. Suppose we wanted to be ven more sure that the range included the mean. The 0.01 proba- ility level of t might be selected to accomplish this. In this case, ıere is a 99 percent chance that the population mean is between 5.80 to 38.90. Now there is only 1 chance in 100 that the con- .dence interval does not include the mean.

## ;ample Size

The larger the sample taken, the closer the sample mean and ariance will be to the population mean and variance. Accord- ıgly, the chances of making an error are reduced. However, ımples cost money. Therefore, it is necessary to strike some alance between the cost of sampling and the cost of making an rror. The confidence interval makes it possible to estimate the umber of samples needed to obtain any given level of precision Ξ). As we saw above, the expression (t) ($S\bar{x}$) defined the spread f the confidence interval. If we think of either the plus (+) or ıinus (−) value of this spread as E, we can define the sample ıze in terms of any desired value of E as follows.

$$(t)\ (S\bar{x}) = E.$$

However, $S\bar{x}$ can be expressed in terms of S and n as:

$$S\bar{x} = \sqrt{\frac{S^2}{n}}.$$

Substituting this for $S\bar{x}$ above gives:

$$(t^2)\ \frac{S^2}{n} = E^2.$$

Solving for n gives the sample size needed to meet the defined :vel of precision E as:

$$n = \frac{t^2S^2}{E^2}.$$

The streambed core data previously presented illustrate the use f this equation. Bjornn (1969 and 1973) did a study to evaluate ıe emergence of chinook salmon fry from sprawning gravels ased on the percentage by weight of sediments less than 0.25 ıch (6.35 mm) in size contained in the gravel. Fry mortality was irectly proportional to the percentage of sediments smaller than .25 inch (6.35 mm). The sample of 20 cores collected in 1971 ontained an average of 32.35 percent fines smaller than 0.25 inch 5.35 mm). Assuming Bjornn's relationship is applicable in the outh Fork of the Salmon River, the fry mortality for the spawn- ıg area sampled would have been 66 percent based on an verage of 32.35 percent fines less than 0.25 inch (6.35 mm) in iameter.

As we saw above, the average percent fines smaller than 0.25 ıch (6.35 mm) can actually range between 27.6 to 37.1 percent ased on the 95 percent confidence interval for the sample of 20 ɔres. The importance of this confidence interval range is better ɔpreciated when expressed in terms of fry mortality. It is ıcorrect to say that mortality was equal to 66 percent based on a ımple mean of 32.35 percent fines. All we can say is that we are 95 percent sure that the actual mortality falls somewhere between 53 and 79 percent based on the sample confidence interval of 27.6 to 37.1 percent sediments smaller than 0.25 inch (6.35 mm) and Bjornn's relationship. Such a range in mortality could have serious management implications. Suppose, for example, that a viable fish population cannot be maintained if fry mortality exceeds 75 percent. The fact that our sample confidence interval indicates there is a chance the 75 percent level can be exceeded would be a red flag for the land manager responsible for maintaining the fish population. The manager needs to know whether or not to institute an expensive spawning gravel cleaning program in order to protect the fish resource. A logical alternative to jumping into such a program would be to check the validity of the sample mean and confidence interval. This could easily be done by increasing the sample size. Although some additional sampling costs would be required, the potential for savings is substantial.

The sample size equation presented above provides a means to estimate the size of sample required for any desired level of precision, in this case, a level of fine sediments less than 0.25 inch (6.35 mm) in size that will result in a fry mortality level of less than 75 percent. Using Bjornn's relationship, 75 percent mortality will be obtained if the streambed contains 36.3 percent sediment smaller than 0.25 inch (6.35 mm). In this case, E is defined as the allowable value of 36.3 percent minus the sample mean of 32.35 percent or:

$$E = 36.3 - 32.35 = 3.95 \text{ percent.}$$

Knowing E and taking $S^2$ from the sample, we have all the components we need to solve the sample size equation, except t. Unfortunately, the value for t is based on n and we are trying to solve for n so it is necessary to use a method of successive approximations. The object is to select a value for n such that the corresponding value of t will produce the same calculated value for n when inserted into the sample size equation. This is illustrated with our example data where $S^2$ is calculated from the sample data and E = 3.95 was determined by the management decision defined above. The $t_{0.01}$ value will be used for the calculation to provide added assurance (at the 99 percent level) that the land manager will not make a mistake.

The first approximation for n might be 31. The $t_{0.01}$ value for n = 31 is 3.659 (using d.f. = n−1 = 30).

Substituting this value for t in the sample size equation:

$$n = \frac{(2.756)^2\ (104.6)}{(3.95)^2} = 51.$$

The selected n value of 31 is obviously too low.

A second n value is selected that is closer to 51, say 45. The $t_{0.01}$ for n = 45 is 2.693 using linear interpolation for t in the table. Substituting this value into the sample size equation gives an n of 49 indicating that the sample size is probably close to 50. The estimated sample size is only an approximation so continued refinement of estimated n is not called for — a total sample size of 50 would be the reasonable recommendation to meet the desired level of precision. A total of 20 cores have already been taken but an additional 30 cores should be randomly collected and analyzed to meet statistical requirements.

## TRANSECT SYSTEM

The transect line intercept is a line determined by two points on opposite streambanks and is useful as the location reference for the measurement of habitat conditions. This line intercept allows for repeated measurements at exactly the same location at different times and yet allows the randomness in site selection needed to meet statistical requirements. The transect line intercept method has been used successfully in many studies that have documented aquatic conditions over space and time (Herrington and Dunham 1967); Platts 1974; Platts and Megahan 1975; Cooper 1976; Duff and Cooper 1978; Megahan and others 1980; Platts in press).

A reference location (point) the transect will pass through is determined in the middle of the channel. The transect intercept line runs from this point and traverses across the stream perpendicular to the main streamflow to establish reference points on the right and left bank. The right bank is determined by the observer facing downstream. To prevent stake movement from soil freezing and high water flows, steel stakes marking these points should be located above high water flows and driven into the ground at least 3 ft (0.91 m).

The next transect line intercept is determined by measuring along the middle of the channel the required spacing interval from the reference location (see appendix 2). This measurement determines the position of the second transect line intercept reference point on the right bank. In an equal-spaced transect group, the distances between points on the center of the channel that determines the transect line locations are equal. Because the line intercept must be perpendicular to the main streamflow, the distance between points on the banks will vary unless the stream channel form is a straight line. This approach is necessary to assure that transects are perpendicular to the flow which avoids introducing bias in measurement, especially stream width, and assists in delineating the boundaries of plots for electrofishing.

If the purpose is to determine or to monitor an environmental condition of the stream at a single point, then one transect is sufficient. For example, a single transect may be located below a point effluent discharge to determine localized changes in the water column over time. A single transect, however, does not allow determination of the environmental condition of an entire stream or a single reach within a stream, but only those conditions existing at a point within a stream.

If the data collected are to be used to describe the aquatic habitat condition of an entire stream or a reach of the stream receiving a point effluent discharge, then a sufficient number of properly spaced transects are required to determine the habitat conditions with acceptable confidence in the results (see appendix 2). The question often asked is how many transects at what intervals are required to insure reliable information with low confidence intervals so that significant change occurring in the stream will be detected. Even though the needed sample size may be known, money and manpower limitations often make it impossible to use the required number and spacing between transects. In this case, specialists should compensate for this by describing the reduction in accuracy in the data collected.

### Transect Cluster

A transect cluster is a group of transects blanketing a stream or stream reach. Three main approaches are used in setting up the cluster. One approach (a multiple transect approach) is to determine the number of transects required to provide the desired sample size and then randomly to select this number of transects so that every point on the stream or reach being evaluated has an equal chance of being selected as a transect line intercept.

The second approach (the multiple station approach) is to randomly select stations throughout the stream or reach and then to group the desired number of transects around each station point. Five grouped transects commonly are used to form one station. Some statisticians favor the station approach because it allows close grouping of the transects. The disadvantage is that the reach between the station is not included in the analysis and can cause bias if the number of stations is inadequate. We have found either the multiple transect or multiple station approach to be adequate, provided the stations or transects are selected randomly and are of sufficient sample size to meet statistical requirements.

The third, and often best, approach is the straitified random station or transect design. This approach assumes that the user has good information on the stream, which then allows intensive sampling in the more complex areas and reduced sampling in the more homogeneous areas. If these requirements are met, better evaluations can then be made with less time and money. This method should not be used, however, unless high confidence exist in the reasons for stratifying the sample.

## ACCURACY AND PRECISION OF MEASUREMENTS

Applying methods that will accurately determine environmental conditions is plagued by both bias, such as systematic observer error, and variability, such as that caused by high natural fluctuations in physical and biological conditions. Extreme fluctuations in the condition of the aquatic habitat and the resulting fish population play havoc with small sample sizes. The large variation caused by these fluctuations is further compounded by bias from observer error. To build confidence in results, the quality in the collection of data must be strictly controlled and the accuracy and precision of the measurements should be provided to the user of the data.

Most of the aquatic habitat attributes discussed in this section have been rated as to their ability to be measured accurately and precisely. The determination of accuracy was based on the ability of the measurement to mirror the expected true mean. The accuracy of the aquatic habitat measurements was estimated by graphing each attribute mean for each stream reach by year and analyzing the fluctuation between the annual means. By subjective evaluating the time trend of the measurements in comparison to how the attribute was believed to have actually performed, accuracy was given a quality rating of poor, fair, good, and excellent. The subjective judgment was further guided by consta[nt] remeasurement of different observers' findings and closely watching how the environmental condition being measured performed over time.

Precision is a measure of the ability of an observer to repeatedly produce the same answer or the ability of different observe[rs] measuring the same condition to produce the same answer. For example, low precision results when an observer measures the streambank undercut and cannot always distinctly define the reference points to obtain the measurement. Thus, the methodology itself, regardless of the ability of the observer, can cause confusion in what to measure. An observer can come up with a different answer from year to year when measuring an undercut that has not changed during this period. The decrease precision shows up especially in those measurements done subje[c]tively. Precision was rated by evaluating the confidence interval obtained in each habitat measurement. The precision of habitat measurements having a confidence interval over ±21 percent was rated poor, ±11 to 20 percent was fair, ±5 to 10 percent was rated good, and anything less than ±5 percent was rated excellent.

An example of subjective measurements causing lowered precision is the evaluation of streambank instability that is subjectively determined from a narrative description. Many things can lower the precision of this meaurement, such as using different observers over time, observers changing their thinking from year to year, the ability of the procedure to measure accurately the attributes, weather conditions at time of measurement, size of stream, amount and type of experience and training, and degree of streambank instability. Some attributes, therefore, are almost impossible to measure with precision. Evaluations of precision were based on the confidence intervals around the mean over time. Most of the personnel collecting the data used in this study had advanced degrees in fisheries or closely related fields, were well trained, and had good-to-excellent equipment.

# STREAM HABITAT EVALUATION

## Water Column

The water column, the medium of support and movement for fish and other aquatic organisms, is controlled by the bank, channel gradient, channel form, stream bottom composition, and the volume of water in the channel. The water's constant three dimensional movement pattern, plus its often unpredictable fluctuations in flow rate, makes it difficult to measure and describe. Care must be taken in time trend studies of effects on fish summer standing crops to sample during base flow, which occurs during late summer in many areas. This will help minimize problems caused by fluctuating flow rates. In streams where flows are controlled by man (dams) and where flows vary day by day, care must be taken to sample uniform flow periods over time, or data collected will not be comparable. If the study is determining high flow effects, then timing of data collection must coincide. The data collection must fit uniform conditions as much as possible to be meaningful.

### Stream Width

Stream width must be determined precisely to accurately measure fish standing crop and biomass per unit area. Platts (1974) found that as stream width increased, certain fish species decreased in number while others increased.

Stream width is the horizontal distance along the transect line from shore to shore along the existing water surface. Width is that length of the transect line intercept over the stream channel and bank that is covered by water. Stream width was recorded to the nearest 1 ft (0.3 m) in this report, but for more accuracy and precision it should be recorded to the nearest tenth of 1 ft (0.03 m).

To provide consistency in measurement, protruding logs, boulders, stumps, or debris surrounded by water are included in the measurement of the water surface. Islands are not included in the measurement. Any solid accumulation of inorganic sediment particles protruding above the water and more than 1 ft (0.3 m) in width is considered an island. The stream width measurement ends when, on approaching the shoreline, any material is not completely surrounded by water and water is only pocketing between the material (fig. 1). These guidelines are necessary to obtain measurement consistency from year to year on the same stream.

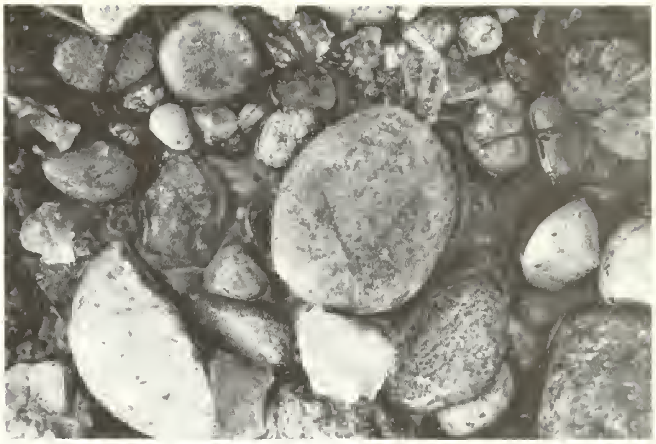

**Figure 1. — Stream width boundaries where materials are no longer surrounded by water.**

On our test streams, stream width exhibited good precision as determined by the 95 percent confidence interval about the mean of ±5.4 percent. In the stream reaches studied, precision and accuracy of the stream width received a year-to-year quality rating of good (see appendix 3).

### Stream Depth

Stream depth is important in providing fish cover, determining stream velocities, and providing a measurement to determine fish standing crop and biomass per unit volume of water. Depth is an important element of the pool quality and fish environment ratings.

Stream depth is the vertical height of the water column from the existing water surface level to the channel bottom measured in tenths of feet (0.03 m). If a streamflow measurement is made, average depth is accurately calculated by dividing the streamflow rate by the product of width and average velocity. If flow data are not available, we determine stream depth as the average of the water depths taken at three locations: one-fourth, one-half, and three-fourths the stream width distance across the transect. The total of the three water measurements is divided by 4 to account for the zero depths at the stream shore where the water surface and the bank or the channel meet. The mathematical basis for this calculation is given in appendix 4.

In our test streams, because of the variation in stream depth and some observer error, the derived sample mean had a 95 percent confidence interval about the mean of ±8.2 percent; precision and accuracy rated good. We have not tested this method on streams averaging over 100 ft (30.5 m) in width, but believe that more than four measurements per transect should be taken when average widths exceed this, especially if transect spacing is wide.

### Stream Shore Water Depth

The stream shore depth is critical for fish, especially young-of-the-year (fig. 2 and 3). Also, this measurement is effective in evaluating those land use activities that could modify the streambank or stream bottom morphology.

The water depth at the stream shore is measured at the shoreline or at the edge of a bank overhanging the shoreline (see fig. 2, angle A1). If the angle formed by the bank as it meets the stream bottom is over 90°, the stream shore water depth reading is always zero. If the angle is 90° or less, the water column goes under the streambank and the measurement of the stream shore water depth is greater than zero (see fig. 2, angles A2, A3, and

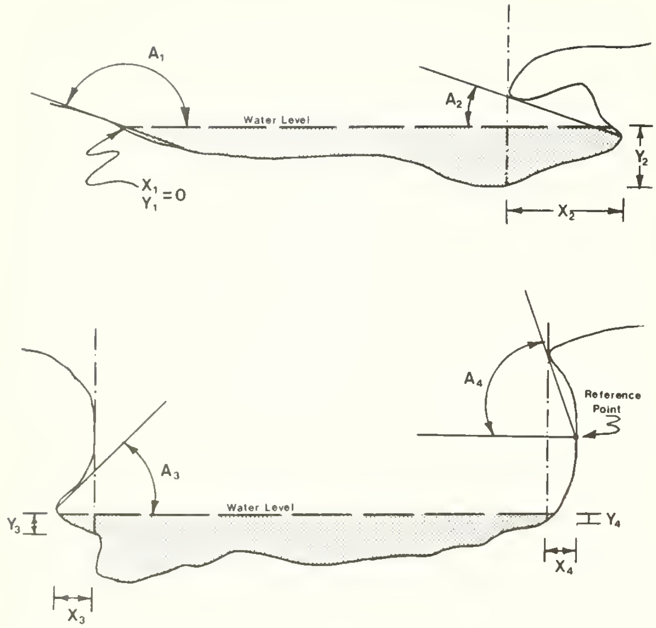


Figure 2. — Hypothetical channel cross sections illustrating bank angle (A), undercut (X), and water depth (Y) measurements.

Figure 3. — Measuring stream shore water depth.

A4). In this report the measurement was taken to tenths of feet and the measurements for both shores were totaled and averaged to get the overall rating for the transect.

Because of the variation in stream shore depth, the test sample mean had a 95 percent confidence interval about the mean of ±16.6 percent. This measurement has fairly wide confidence intervals, mainly because of the high variability and the difficulty in standardizing the technique. We did find, however, that the precision and accuracy rated good from year to year.

## Pool

The pool-riffle ratio and pool quality have long been used to determine a stream's potential for rearing fish. A pool is that area of the water column that has slow water velocity and is usually deeper than a riffle or a run (fig. 4). The streambed gradient of the pool itself is often near zero and often concave in shape. The water surface gradient of pools at low flow is close to zero. Pools often contain large eddies with widely varying directions of flow compared to riffles and runs where flow is nearly exclusively downstream. Pools usually are formed around bends or around large-scale obstructions that laterally constrict the channel or cause a sharp drop in the water surface profile.

The measurements to determine the amount of pool, glide, run, and riffle are made directly along the transect line. In this report, pool width has been measured to the nearest foot (0.3); for better precision it should be measured to the nearest tenth of a foot, but only if pools can be defined to that detail. Problems arise in identifying these classes from each other because they are not separated by distinct boundaries.

Because of the variation in the amount of pool within an intercept line crossing the water column, the 95 percent confidence interval about the mean was ±10.3 percent and year-to-year precision and accuracy rated poor in our studies. Confidence intervals around the mean are fairly low because observers, even though they may have interpreted the pool boundaries incorrectly, did so in a uniform manner. The bias arises during the next rating, especially if a new observer is used, when a different interpretation enters into the rating criteria. As a result, the percent pool mean may fluctuate over time even though no changes occur in the water column.

Figure 4. — Determining the point on the transect line that separates the riffle from the pool.

## Pool Quality

Pool quality (Platts 1974, and rating system in table 1) estimate the capability of the pool to provide fish survival and growth requirements. Platts (1974) found a good relationship between high quality pools and high fish standing crops. Small, shallow pools, needed by young-of-the-year fish to survive, rate low in quality, however, even though they are essential for their survival The user should remember that this rating system was developed mainly from the habitat needs of fish of catchable size. In actuality, it takes a combination of pool classes to build a productive fishery.

This rating (table 1) requires that direct measurements of the greatest pool diameter and depth be combined with a cover analy sis. Pool cover is any material or condition that provides protection to the fish from its predators or competitors, such as logs, organic debris, overhanging vegetation within 1 ft (0.3 m) of the water surface, rubble, boulders, undercut banks, or water depth.

As the transect line crosses the water column surface, it can intercept one pool, many pools, pools and riffles, or riffles only. If more than one pool is intercepted by the transect line, then po widths times their respective quality ratings are summed and this

**Table 1.** — Rating of pool quality; designed for streams between 20 and 60 ft in width

| | Description | Pool rating |
|---|---|---|
| 1A | If the pool maximum diameter is within 10 percent of the average stream width of the study site | Go to 2A, 2B |
| 1B | If the maximum pool diameter exceeds the average stream width of the study site by 10 percent or more | Go to 3A, 3B |
| 1C | If the maximum pool diameter is less than the average stream width of the study site by 10 percent or more | Go to 4A, 4B, 4C |
| 2A | If the pool is less than 2 ft in depth | Go to 5A, 5B |
| 2B | If the pool is more than 2 ft in depth | Go to 3A, 3B |
| 3A | If the pool is over 3 ft in depth or the pool is over 2 ft depth and has abundant fish cover[1] | Rate 5 |
| 3B | If the pool is less than 2 ft in depth, or if the pool is between 2 and 3 ft and the pool lacks fish cover | Rate 4 |
| 4A | If the pool is over 2 ft with intermediate[2] or better cover | Rate 3 |
| 4B | If the pool is less than 2 ft in depth but pool cover for fish is intermediate or better | Rate 2 |
| 4C | If the pool is less than 2 ft in depth and pool cover is classified as exposed[3] | Rate 1 |
| 5A | If the pool has intermediate to abundant cover | Rate 3 |
| 5B | If the pool has exposed cover conditions | Rate 2 |

[1]If cover is abundant, the pool has excellent instream cover and most of the perimeter of the pool has a fish cover.
[2]If cover is intermediate, the pool has moderate instream cover and one-half of the pool perimeter has fish cover.
[3]If cover is exposed, the pool has poor instream cover and less than one-fourth of the pool perimeter has any fish cover.

total divided by the total pool width to give the weighted average pool rating.

We had some difficulty in determining pool quality in our studies, but the 95 percent confidence interval about the mean was only ±8 percent; therefore, precision was good. Problems arise, however, in getting high accuracy, mainly because of observer error in discriminating pool from riffle, and the key (table 1) was designed for streams between 20 and 60 ft (6.1 and 18.3 m) in width, but was applied to streams from 1.5 to 150 ft (0.5 m to 45.7 m) in width. We found that table 1 should be modified for use on small or large streams.

### Pool Feature

Pool feature is designed to classify the condition that formed or is maintaining the pool. Pool features by itself apparently does not have any influence on fish standing crop or species composition as it is the quality of the pool that counts and not the process that formed it (Platts 1974). The main use of this classification is to track changes in the stream caused by beaver or human activities, such as channelization, dams, ponds, or culverts, and to make sure this bias does not enter into the interpretation of a time trend analysis. No confidence levels are given for this measurement. Features forming pools are coded as follows:

| Feature forming the pool | Code |
|---|---|
| Log, tree, root, stump, brush, or debris | 1 |
| Channel meander | 2 |
| Rubble or gravel | 3 |
| Boulder or bedrock | 4 |
| Stream channel[2] | 5 |
| Fine sediment | 6 |
| Streambank | 7 |
| Culvert, bridge, or other manmade object | 8 |
| Beaver dam or tunnel | 9 |

### Riffle

In many streams, riffles produce most of the fishes' aquatic food, form spawning areas, and provide some cover for rearing. Riffles are portions of the water column where water velocity is fast, stream depths are relatively shallow, and the water surface gradient is relatively steep. Channel profile is usually straight to convex. Fish expend high amounts of energy in riffles to maintain position.

Presently, we will record only the pool and riffle classes, because we have found it difficult to make all five (pool, riffle, run, glide, and pocket water) separate classifications. Glide and run are difficult to classify because they tend to fall into both the pool (glide) or riffle (run) classifications. In the results reported here, all glides and slower moving runs are considered pools. The faster moving runs are classified as riffles. The Blackfoot River in eastern Idaho was the only stream for which we felt we could accurately evaluate runs because they stand out, make up a large proportion of the water column, and are easily identified. As discussed in the section on pools, we had difficulties classifying riffles because on most streams there are no sudden breaks in the boundaries separating pools and riffles. Streams with high (more than 3 percent) or low (less than 0.5 percent) channel gradients are the easiest to classify.

In our studies, we had a 95 percent confidence interval about the percent riffle mean of ±17 percent. This is not good, but it is the best that we could expect without better guidelines to delineate the riffle areas. Precision and accuracy were poor.

### Glide

A glide is that area of the water column that does not form distinguishable pools, riffles, or runs because it is usually too shallow to be a pool and too slow to be a run. This type of a water column resembles the flow that would be found in a shallow canal. Water surface gradient over the glide is nearly zero. We have not tested this variable sufficiently to draw any conclusions on its reliability for measurement other than it is difficult to classify.

### Run

A run is that area of water column that does not form distinguishable pools, riffles, or glides, but has a rapid nonturbulent flow. A run is usually too deep to be a riffle and too fast to be a pool. Runs are like low incline planes where all water flows the

[2]Used when the pool-forming feature cannot be determined.

same fast pacc, but at a pace not fast enough to cause much surface rippling. The channel form under a run is usually very uniform and the plane flat. As with the glide classification, we do not have enough data to interpret the precision and accuracy of measurement and we suggest caution in the use of this classification.

### Pocket Water

Pocket water (alcoves) consist mainly of small pools behind boulders, rubble, or logs. They form small, shallow microniches where feeding trout and other fish species rest away from the faster waters surrounding the pocket. Pocket water usually supports a much lower fish standing crop than most other pools because of the small pool size and depth. They are usually rated in the pool quality analysis as class 1 or 2 pools. Seldom do they ever get wide enough or deep enough to be rated as class 4 or 5 pools. We have not tested this variable sufficiently to determine its usefulness.

### Pool-Riffle Ratio

Pool-riffle ratio is the length or percent of riffle divided into the length or percent of pool. This ratio is a measurement used to predict the stream's capability of providing resting and feeding pools for fish and riffles to produce their food and support their spawning. The common interpretation is that a ratio of 1 to 1 is optimum. However, Platts (1974) found that the highest salmonid fish standing crops in the South Fork Salmon River drainage were in stream reaches with a ratio of 0.4:1. Some streams, however, having a high pool-riffle ratio are known to be high producers of salmonids. The precision and accuracy of the pool-riffle ratio can be no more accurate than can be obtained for pool and riffle individually.

### Streamflow Measurement

The water and surrounding channel comprise a complex and dynamic hydraulic system where variable waterflows and associated changes in width, depth, and velocity interact with such factors as sediment transport, channel shape, bank cutting, and size of bottom materials. Fish can respond in a number of ways to variations in these factors, depending on species, age, and time of year. As an independent variable driving the system, flow is an important concern for any stream environment study.

The U.S. Geological Survey is the Federal agency responsible for the national streamflow measurement program. The Survey has developed a number of guides for making flow measurements in its publication series entitled "Techniques for Water-Resources Investigations of the United States Geological Survey" (Buchanan and Sommers 1969).

Flow (Q) is expressed as volume of water moving past a given stream cross section per unit of time and is determined by multiplying the cross sectional area of water (A) in square feet times flow velocity (V) in feet per second to give the traditional units of cubic feet per second. Unfortunately, flow velocity varies greatly within a channel, with both depth and width. Thus, it is not possible to measure streamflow with a single measurement of velocity. Rather, the channel must be broken into a number of sections (fig. 5) to account for variations in velocity with width.

The total flow calculation was based on the sum of the flows for individual sections as follows:

$$1.\ Q = \sum_{i=1}^{n} (w_{i+1} - w_i)\left(\frac{d_i + d_{i+1}}{2}\right)\left(\frac{v_i + v_{i+1}}{2}\right)$$

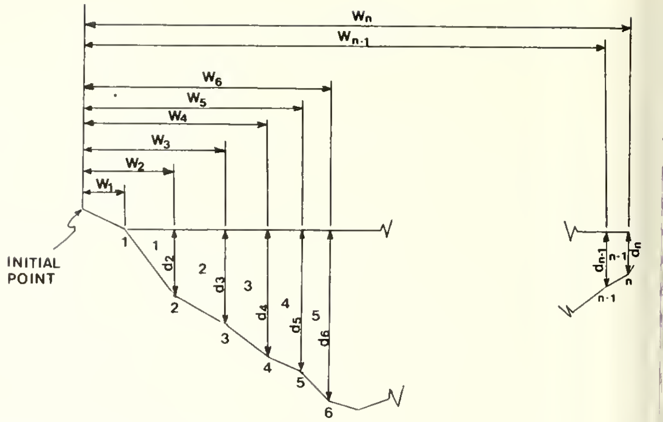


**Figure 5. — Shown is the cross section design used for measurement of streamflow.**

where:

n = the total number of individual sections

$w_i$ = horizontal distance from the initial point

$d_i$ = water depths for each section

$v_i$ = measured velocity for each section.

The flow for each individual section is calculated and section flows are summed to get the total. For example, the flow for section 4 is:

$$2.\ Q_4 = (w_5 - w_4)\left(\frac{d_5 + d_4}{2}\right)\left(\frac{v_5 + v_4}{2}\right).$$

At distances $w_1$ and $w_n$, the velocities are always 0. Values of $D_i$ are also 0 at these distances, except when a vertical bank occurs as shown on the right bank in figure 5.

The number of subsections used in any flow measurement depends on the variability of velocities within the channel. Usually, at least 20 measurement points should be used unless the channel is extremely regular in both bottom elevation and velocity distribution. Measurement points are taken at all breaks in the gradient of the stream bottom and where any obvious changes in flow velocity occur within the channel. It is advisable to space the partial sections so that no partial section has more than 10 percent of the total flow contained in it. Equal widths of partial sections across the entire cross section are not recommended unless the channel cross section is extremely uniform.

Velocity variations with depth are accounted for by measuring flow at depths where velocity is equal to the average velocity for the total depth. Referring to figure 5, the proper measurement depths vary with water depth as follows:

a. If $d_i < 0.3$ ft (0.1 m), measure $v_i$ at 0.5 $d_i$.

b. If 0.3 ft (0.1 m) $< d_i < 2.5$ ft (0.76 m), measure $v_i$ at 0.6 $d_i$.

c. If $d_i > 2.5$ ft (0.76 m), measure $v_i$ at 0.2 and 0.8 d and average.

All measurements are referenced to the water surface. For $d_i$ values of less than 0.3 ft (0.1 m) or greater than 2.5 ft (0.76 m), the reference point makes no difference. However, for depths ranging from 0.3 to 2.5 ft (the most common range sampled in aquatic habitat studies) the velocity is taken at 0.6 $d_i$ measured from the water surface. This is equivalent to measuring up 0.4 $d_i$ from the bottom.

Velocity is measured with a current meter attached to a rod or cable for measuring depth. The rod is adjustable and can be set at the proper measurement depth. Many kinds of current meters are available, some of which require counting the number of revolutions of a rotor wheel for a specific period of time (usually, at least 30 seconds). The calculated number of revolutions per second is then used to determine velocity from a rating curve supplied with the meter. Current meters that provide direct measurements of flow velocity are also available. Current meters are precise instruments and should be treated as such. Operation and maintenance must be followed according to the manufacturer's directions in order to assure reliable data.

### Solar Radiation

Total light incident on the stream and the resulting heat load are important factors regulating biological activity in the stream. Changes in stream heat load following timber harvest in the riparian zone have been a particular concern because of the potential of deleterious effects on fish caused by sharp increases in maximum water temperatures. Brown (1969) found temperature changes closely related to changes in solar radiation input to the channel following vegetation removal. He developed a procedure to estimate the change in annual maximum water temperature in tributary streams following clearcutting. Wooldridge and Stern (no date) tested Brown's procedure in Washington State and refined the procedure to account for partial removal of streamside vegetation. Their technique involves the use of a fisheye camera photo in conjunction with a polargraph overlay to determine incident shortwave radiation input.

We have used the angle of sun arc as an index of solar radiation input. This is defined in appendix 5.

## Channel Morphology

The riparian zone is composed of two dominant features, the flood plain and the channel. The channel is further subdivided into banks and bottom. All of these features represent the interaction between the flow regime for the stream, the quantity and character of sediment movement past the channel section of interest, and the character of the materials making up the bed and banks of the stream. Channels are carved by the tractive forces created by flowing water; so it is logical that some relatively frequent flows dominate the channel-forming process. On the average, flows with a return interval of about 1.5 years or less can be contained within the stream channel, whereas greater flows spread out onto the flood plains. The flow that is just large enough to completely fill the channel — the so-called bank-full flow — is the dominant flow shaping stream channels. The morphology of the channel and flood plain are all referenced to this flow level. For purposes of aquatic environment inventory, the flood plain and components of the channel are defined as follows:

**Channel** — That cross section containing the stream that is distinct from the surrounding area due to breaks in the general slope of the land, lack of terrestrial vegetation, and changes in the composition of the substrate materials. The channel is made up of streambanks and stream bottoms.

**Banks** — The portion of the channel cross section that tends to restrict lateral movement of water. The bank often has a gradient steeper than 45° and exhibits a distinct break in slope from the stream bottom. Also, an obvious change in substrate materials may be a reliable delineation of the bank.

**Stream bottom** — The portion of the channel cross section not classified as bank. The bottom is usually composed of stream sediments or water-transported debris and may be covered by rooted or clinging aquatic vegetation. In some geologic situations, the stream bottom may consist of bedrock rather than sediments.

**Flood plain** — Area adjacent to the channel that is occasionally submerged under water. Usually the flood plain is a low gradient area well covered by various types of riparian vegetation.

Some actual channel cross sections collected on Frenchman Creek in the mountains of southern Idaho illustrate the nomenclature. The channel cross sections were surveyed using the generalized sag tape procedure (Ray and Megahan 1978). The cross sections are plotted using the same horizontal and vertical scales to avoid exaggeration of channel features. Figure 6 shows a well-defined channel with obvious breaks between the channel and the flood plain. The tops of both banks are usually close to the same elevation and are distinct from the flood plain because of breaks in slope gradient as shown in this example. The bottom of the left bank is very well defined compared to the right bank. There is a slight slope break at the water line on the right bank suggesting a possible change in the composition of the substrate material at this point. Field examination showed a very definite transition from bottom sediments to fine-textured, organic bank materials at this point.

It is almost impossible to conduct aquatic surveys under bank-

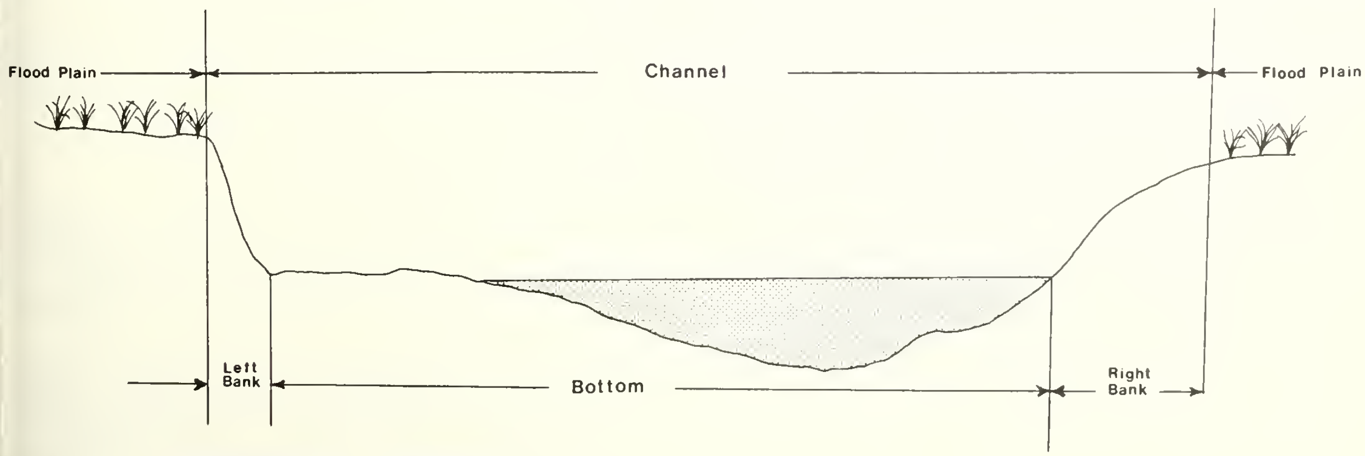


**Figure 6. — A well-defined stream channel (downstream view).**

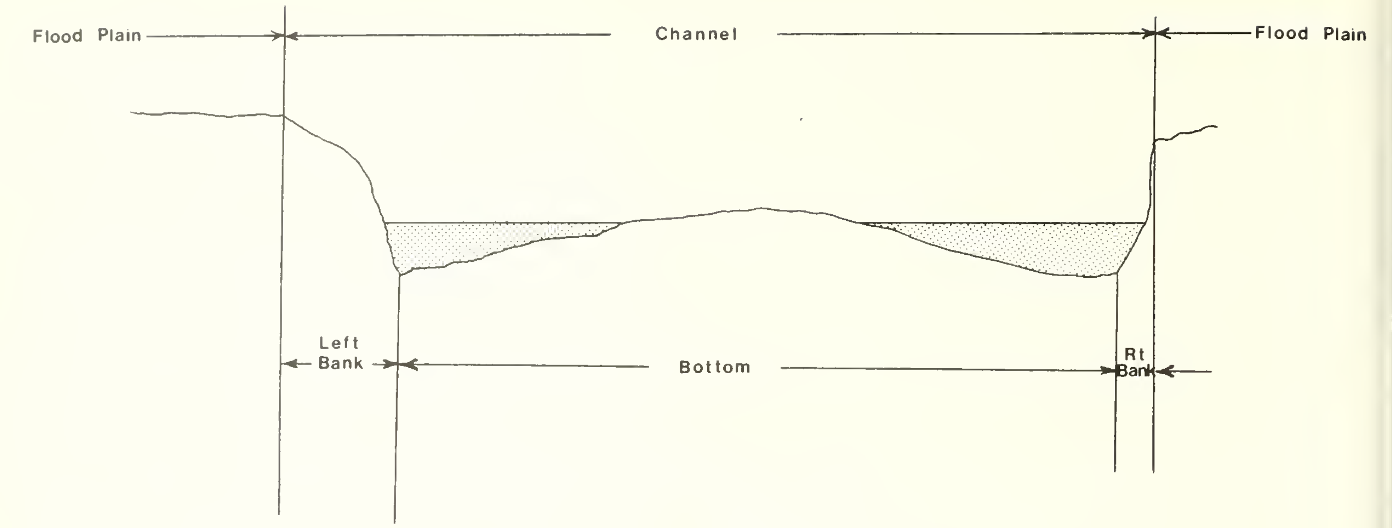


Figure 7. — A well-defined stream channel with concentrated low flows and exposed bottom (downstream view).

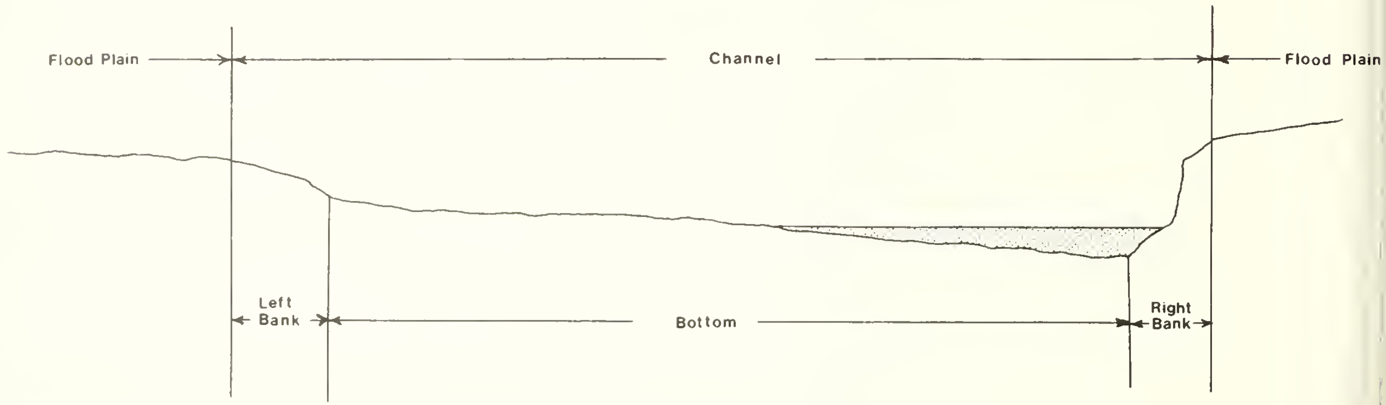


Figure 8. — Stream channel cross channel section on a bend in a stream.

full flow conditions for a variety of reasons, not the least of which is safety. Consequently, aquatic data are almost always collected during low flow periods when the channel is flowing far below bank-full capacity. Commonly, flow levels are so low at this time that part of the stream bottom is exposed, as was the case in all three of these example cross sections.

Figure 7 shows a well-defined channel and banks with low flows concentrated on both sides of the bottom and exposed bottom in the middle.

Figure 8 illustrates a common situation found when a cross section site falls on a bend in the stream. In these cases, the inside of the bend is a zone of sediment deposition and the outside is a zone of erosion for bottom and banks. The result is an asymmetrical cross section as shown in the figure. Oftentimes, it is difficult to delineate the bank, especially the bottom edge, on the inside of the bend because of sediment deposition. The left bank shown in the figure was delineated on the basis of a break in grade and vegetation growth at the top of the bank and a change from lithic sediments to organic materials, plus a small grade change at the bottom of the bank.

Figure 8 also illustrates another situation that occurs with some cross sections, especially asymmetrical cross sections, where tractive forces near the bank cause erosion. However, the top of the bank is usually stabilized by vegetation roots allowing the bank to undercut. Bank undercutting is most common along the outside of bends in the channel, but is not restricted to bends — it can, and commonly does, occur on straight channel reaches as well. Sometimes, the undercut bank collapses, causing a stairstep appearance at the bottom of the bank as shown on the bottom of right bank in figure 8.

## Streambank

Well vegetated banks are usually stable regardless of bank undercutting, which provides excellent cover for fish. Valuable fish cover is ultimately lost when bank vegetation decreases, when banks erode too severely, or when banks undercut too quickly and slough off into the stream bottom.

### Streambank Soil Alteration

Certain land uses, especially livestock grazing, can start the modification of a stream by causing instability of the bank (Platts in press). This streambank alteration rating, therefore, may provide a warning system for changes that will eventually affect fish populations.

The streambank alteration rating reflects the changes taking place in the bank from any force (table 2). The rating is separated into five classes. Each class, except the one with no alteration, has an evaluation spread of 25 percentage points. Once the class is determined, the observer must decide the actual percent of

Table 2. — Streambank soil alteration rating

| Rating | Description |
|---|---|
| *Percent* | |
| 0 | Streambanks are stable and are not being altered by water flows or animals. |
| 1 to 25 | Streambanks are stable, but are being lightly altered along the transect line. Less than 25 percent of the streambank is receiving any kind of stress and if stress is being received, it is very light. Less than 25 percent of the streambank is false, broken down, or eroding. |
| 26 to 50 | Streambanks are receiving only moderate alteration along the transect line. At least 50 percent of the streambank is in a natural stable condition. Less than 50 percent of the streambank is false, broken down, or eroding. False banks are rated as altered. Alteration is rated as natural, artificial, or a combination of the two. |
| 51 to 75 | Streambanks have received major alteration along the transect line. Less than 50 percent of the streambank is in a stable condition. Over 50 percent of the streambank is false, broken down, or eroding. A false bank that may have gained some stability and cover is still rated as altered. Alteration is rated as natural, artificial, or a combination of the two. |
| 76 to 100 | Streambanks along the transect line are severely altered. Less than 25 percent of the streambank is in a stable condition. Over 75 percent of the streambank is false,[1] broken down, or eroding. A past damaged bank, now classified as a false bank, that has gained some stability and cover is still rated as altered. Alteration is rated as natural, artificial, or a combination of the two. |

[1]False banks are those banks which have been cut back by cattle and are no longer immediately adjacent to the stream. They can become stabilized by vegetation, but base flows are usually too far removed from the stream to provide fish cover.

instability. Streambanks are evaluated on the basis of how far they have moved away from optimum conditions for the respective habitat type. Therefore, the observer must be able to visualize the streambank as it would appear under optimum conditions. Any natural or artificial alteration deviating from this optimum condition is included in the evaluation. This visualization makes uniformity in rating an alteration difficult, because it is difficult to train all observers to visualize the same optimum bank condition. Natural alteration is any change in the bank produced by natural events. Artificial alteration is any change obviously produced by exotic force. Trampling by man or livestock, disturbance by bulldozers, etc., are examples of artificial changes.

Natural and artificial alterations are reported individually, but together they cannot exceed 100 percent. Only that part of the streambank intercepted by the channel cross section transect line enters the evaluation in order to reduce the confidence intervals. Channel cross section transect lines have no end. The line crosses both streambanks as the channel transect line is extended. Rating the complete bank as a unit between groups of transects in our studies resulted in greater observer error.

It is commonly difficult to distinguish artificial from natural alterations; if there is any doubt, the alteration is classified as natural. It is possible to have artificial alterations cover already existing natural alterations and vice versa. Only the major type of alteration on a unit area enters the rating system in this case.

Table 3. — Streambank vegetative stability rating

| Rating | Description |
|---|---|
| 4 (Excellent) | Over 80 percent of the streambank surfaces are covered by vegetation in vigorous condition or by boulders and rubble. If the streambank is not covered by vegetation, it is protected by materials that do not allow bank erosion. |
| 3 (Good) | Fifty to 79 percent of the streambank surfaces are covered by vegetation or by gravel or larger material. Those areas not covered by vegetation are protected by materials that allow only minor erosion. |
| 2 (Fair) | Twenty-five to 49 percent of the streambank surfaces are covered by vegetation or by gravel or larger material. Those areas not covered by vegetation are covered by materials that give limited protection. |
| 1 (Poor) | Less than 25 percent of the streambank surfaces are covered by vegetation or by gravel or larger material. That area not covered by vegetation provides little or no control over erosion and the banks are usually eroded each year by high water flows. |

The cross sectional profile methods to be discussed later hopefully will replace this variable; however, the profiles do not determine whether changes in the streambank are caused by natural or artificial forces. Because the 95 percent confidence interval ($\pm 12.3$ percent) around the mean and observer variation is quite wide, interpreting the data must be done carefully. Between the streams studied, there is a wide spread in the precision and accuracy of measurements. Precision was rated fair to good, but accuracy was rated mainly poor to fair, which means caution should be used in evaluating the data.

## Streambank Vegetative Stability

The ability of vegetation and other materials on the streambank to resist erosion from flowing water was rated (table 3). The rating relates primarily to stability generated by vegetative cover, except in those cases where bedrock, boulder, or rubble stabilizes the streambanks. The rating takes all these protective coverings into account. The rated portion of the bank or flood plain includes only that area intercepted by the transect line within 5 ft (1.5 m) of the stream to the top of the bank. Surprisingly, the confidence intervals around the means from our study sites are quite low (about $\pm 3$ percent); however, year-to-year precision and accuracy rated only fair. Therefore, the user should be cautious in its use.

## Streambank Undercut

Streambank undercut provides cover for fish and often is considered a condition favorable to producing high fish biomass. Undercut is a good indicator of how successfully streambanks are protected under alternative land uses, such as livestock grazing and road building. The undercut, if it exists, is measured with a measuring rod directly under the transect line from the furthest point of protrusion of the bank to the furthest undercut of the bank (fig. 2); the water level does not influence this reading. In the studies reported here, the measurement was recorded to the nearest tenth of a foot. If more than one undercut occurs under the transect, only the dominant undercut is recorded.

The 95 percent confidence intervals around the means in our studies (±18.5 percent) are wide; year-to-year precision and accuracy, however, are rated good. The major cause of the wide confidence interval is that the two points that define the undercut measurements are difficult to accurately determine. Then, too, there is naturally high variation in undercuts.

### Stream Channel-Bank Angle

Fish often congregate near the streambank for the edge effect it provides. If the bank has been cut away and moved back from the water column, valuable rearing habitat is lost. This measurement is effective for monitoring land uses that can change the morphology and location of the streambank.

A clinometer is used to measure the angle formed by the downward sloping streambank as it meets the more horizontal stream bottom (fig. 9 and 10). If the streambank is undercut, the angle is always less than 90°. The angle is determined directly from the clinometer placed on the top of the rod as it forms the angle determined by the protruding edge of the bank to the midpoint of the undercut under the transect line (fig. 4).

**Figure 9. — Using a clinometer to measure a bank angle of 45°.**

**Figure 10. — Using a clinometer to measure a bank angle of 145°.**

If the bank is not undercut, then the angle is 90° or more and is read from the bank side by placing the clinometer on the top of the measuring rod that is alined parallel to the streambank along the transect. The clinometer reading is subtracted from 180° to get the bank angle.

A streambank angle over 90° is easily read with precision and accuracy. An angle less than 90° is more difficult to read as multiple undercuts can complicate the bank profile making it difficult to determine the points delineating the angle. The key is to include the midpoint of the dominant undercut in the bank profile. The 95 percent confidence intervals around the means in our studies are quite narrow (±4.4 percent) and year-to-year precision and accuracy rate good.

## Stream Bottom

The stream bottom is bounded by the streambanks and is the relatively level substrate plane over which the water column moves. The substrate is the mineral or organic material that forms the bed of the stream. During low flows the water column may recede from the streambank and not cover all of the stream bottom. During high flows the main channel bottom, overflow channels, and the streambanks are often completely covered with water. The stream bottom merges into the bank where the bottom rises to a steep angle toward the channel margin.

If a stream can only be sampled once, the low flow period is best since bed composition is relatively stable during this period. However, if percent fines in the redds is being used to determine their quality, it should be recognized that summer measurements of channel composition may not present a true picture of redd composition during winter high flow months when the fish eggs and alevins are in the gravel. Fine sediment measurements during summer conditions, at the time the major fish biomass is being produced, is important.

### Channel Elevation

Channel elevation can be an indicator of certain conditions, such as the amount of channel icing or summer water temperature that can affect fish. Channel elevations can be determined within ±40 ft (12.0 m) from U.S. Department of the Interior Geological Survey topographic quadrangle maps with 40-ft (12.0 m) contours as long as the transect sites can be correctly located on the map. If maps are not available, altimeters can be used. These instruments are accurate if calibrated each morning at an official Geological Survey elevation marker and calibrated again during the day if barometric pressure changes significantly. The accuracy of "Thomen" hand-held altimeter measurements checked against a quadrangle map was within ±50 ft (15.3 m) of the map elevation.

### Channel Gradient

Channel gradient is an important variable regulating stream velocity and as such is a concern for aquatic environment studies. Channel gradient is defined as the drop in water surface elevation per unit length of channel. Usually, channel gradients are taken in conjunction with channel cross section measurements. For our study streams, we measure the difference in water surface elevation between points located 100 ft (30.5 m) upstream and 100 ft downstream from each cross section. This assumes that both the channel and the water surface have the same gradient. Horizontal distance between upstream and downstream points is measured along the bank following the general longitudinal shape of the water surface. When measuring distances, care is taken to strike a balance between measuring every minor fluctuation in the edge of the water surface, on one hand, to measuring across bends in the general shape of the channel, on the other. The channel gradient must be uniform for the 200-ft (31-m) long channel reach (100 ft upstream and downstream from a point) included in the measurement. If this is not the case, the distance should be reduced accordingly to wherever an obvious break in channel gradient occurs.

Elevations for determining gradient are read using an engineer's level and a stadia rod held at the water surface (normally at the water's edge). It may not be necessary to use an engineer's level for some applications. For example, hand level or clinometer measurements may provide acceptable gradient measurements in the design of channel improvement structures.

### Channel Sinuosity

Channel sinuosity is defined as the ratio of channel length between two points on a channel to the straight line distance between the same two points. The ratio can vary from 1 for straight channels to 4 or more for strongly meandering channels. The value is useful for providing gross comparisons of aquatic habitat conditions between streams or reaches within the same stream. In general, low sinuosity suggests steeper channel gradient, fairly uniform cross section shapes, limited bank cutting, and limited pools. High sinuosity is associated with lower gradients, asymmetrical cross sections, overhanging banks, and bank pools on the outside of curves. The last situation is common on channel reaches in meadow areas.

Sinuosity should be determined over a channel reach long enough to make the value meaningful. This is based on the size of the channel and the nature of the reach. We use a distance of 20 times the bankful width to determine sinuosity.

### Stream Channel Substrate

**Surface visual analysis.** — The composition of the channel substrate (table 4) is determined along the transect line from streamside to streamside. A measuring tape is stretched between the end points of each transect, and each 1-ft (0.3-m) division of the measuring tape is projected by eye vertically to the stream bottom and the materials assigned to the major sediment class observed for each 1-ft division of the bottom (table 4). For example, 1 ft of stream bottom containing 4 inches rubble, 6 inches gravel, and 2 inches fine sediment would be classified as 1 ft of gravel. With a large enough sample it is assumed that any bias in assigning the dominant sediment class would be compensated for. The individual 1 ft classifications are totaled to obtain the amount of bottom in each of the size classifications and these are totaled to equal the total transect width. We use reference sediment samples embedded

**Table 4.** — Classification of stream substrate channel materials by particle size from Lane (1947) based on sediment terminology of the American Geophysical Union[1]

| Class name | Size range[2] | | | | Approximate sieve mesh openings per inch | |
|---|---|---|---|---|---|---|
| | Millimeters | | Microns | Inches | Tyler screens | United States standard |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Very large boulders | | 4,096-2,048 | | 160-80 | | |
| Large boulders | | 2,048-1,024 | | 80-40 | | |
| Medium boulders | | 1,024-512 | | 40-20 | | |
| Small boulders | | * 512-256 | | 20-10 | | |
| Large cobbles | | 256-128 | | 10-5 | | |
| Small cobbles | | * 128-64 | | 5-2.5 | | |
| Very course gravel | | 64-32 | | 2.5-1.3 | | |
| Course gravel | | * 32-16 | | 1.3-0.6 | | |
| Medium gravel | | 16-8 | | 0.6-0.3 | 2-1/2 | |
| Fine gravel | | 8-4 | | 0.3-0.16 | 5 | 5 |
| Very fine gravel | | * 4-2 | | 0.16-0.08 | 9 | 10 |
| Very course sand | 2-1 | 2.000-1.000 | 2,000-1,000 | | 16 | 18 |
| Course sand | 1-1/2 | *1.000-0.500 | 1,000-500 | | 32 | 35 |
| Medium sand | 1/2-1/4 | 0.500-0.250 | 500-250 | | 60 | 60 |
| Fine sand | 1/4-1/8 | 0.250-0.125 | 250-125 | | 115 | 120 |
| Very fine sand | 1/8-1/16 | *0.125-0.062 | 125-62 | | 250 | 230 |
| Course silt | 1/16-1/32 | 0.062-0.031 | 62-31 | | 270 | |
| Medium silt | 1/32-1/64 | 0.031-0.016 | 31-16 | | | |
| Fine silt | 1/64-1/128 | 0.016-0.008 | 16-8 | | | |
| Very fine silt | 1/128-1/256 | 0.008-0.004 | 8-4 | | | |
| Coarse clay | 1/256-1/512 | 0.004-0.0020 | 4-2 | | | |
| Medium clay | 1/512-1/1,024 | 0.0020-0.0010 | 2-1 | | | |
| Fine clay | 1/1,024-1/2,048 | 0.0010-0.0005 | 1-0.5 | | | |
| Very fine clay | 1/2,048-1/4,096 | 0.0005-0.00024 | 0.5-0.24 | | | |

[1]Reprinted with permission from *Sedimentation Engineering*, edited by Vito A. Vanomi and published by American Society of Civil Engineers, New York.

[2]Recommended sieve sizes are indicated by an asterisk (*).

Table 5. — Classification of stream substrate channel materials by particle size

| Particle diameter size | | Sediment classification |
|---|---|---|
| *Millimeters* | *Inches* | |
| 610.0 or more | 24.0 or more | Large boulder |
| 305.0 to 609.0 | 12.0 to 23.9 | Small boulder |
| 76.1 to 304.0 | 3.0 to 11.9 | Rubble (cobble) |
| 4.81 to 76.0 | .19 to 2.9 | Gravel |
| .83 to 4.71 | .033 to .18 | Fine sediment — large |
| .83 or less | .033 and less | Fine sediment — fine |

in plastic cubes placed on the bottom to help classify the smaller sediment class break sizes.

The classification in table 4 presents the accepted terminology and size classes for stream sediments and should be adapted and used by all specialists working with stream channel substrates. This is the only way all disciplines will use a single standardized procedure. The classification is well suited to the needs of biologists. Because our work was initiated in 1966, we used the classification shown in table 5, and the interpretations of boulder, rubble, gravel, and fine sediments in this study are based on this classification.

*Boulder.* — Boulder is stratified into two classes, large and small. Percent boulder in the channel can be determined fairly accurately if there is not a high amount of rubble between the 11- to 11.9-inch (279.4- to 302.3-mm) class. The 95 percent confidence interval around the mean of percent boulder (about ±40.9 percent) is high in our analysis in those streams containing boulder, because boulder makes up such a low percentage of the channel and is highly variable. In boulder-dominated channels these intervals can be expected to decrease greatly. Year-to-year precision was poor but accuracy in this measurement was rated good because this substrate class is easy to identify and measure. Also, there is little instream movement of boulder from year to year so time-trend analyses also have good accuracy and precision.

*Rubble.* — Rubble stabilizes the stream bottom, provides habitat for fish rearing, and is the substrate where much of the food for fish is produced. Measurement of the amount of rubble in the channel in our studies, like boulder, had high confidence intervals around the means (±35.9 percent) because of the high natural variation in the amount of rubble and the difficulty in accurate classification of those particle sizes between 2.5 to 3.5 inches (63.5 to 88.9 mm) in diameter. Year-to-year precision was low.

*Gravel.* — Gravel is important for spawning, incubation of embryos, and as substrate for some aquatic invertebrates. This particle size is a major sediment component in many small streams in our area. In our studies, the 95 percent confidence intervals around the means (about ±6 percent) is much lower than for rubble and boulder because gravel is more uniformally distributed in the channel. Year-to-year precision and accuracy ratings, however, were poor because the identification of gravel at both ends of the size spectrum is difficult. Particle sizes between 2.5 and 3.0 inches (63.5 and 76.1 mm) tend to be called rubble, whereas particles near the 0.19-inch (4.75-mm) range are often classified as fine sediment. Different sediment size classes embedded in plastic that can be laid on the channel for comparison help considerably in eliminating this bias.

*Fine sediment.* — Fine sediment is separated into two classes consisting of large fine sediment and small fine sediment. The reason for the separation is that the large fine particles can trap alevins in the redds, but the small fine particles decrease water permeability through spawning gravels. In our studies, the 95 percent confidence intervals around the means (±27.7 percent for large fine sediment and ±17.3 percent for small fine sediment) are wide. Year-to-year precision and accuracy rate fair; so some difficulty exists in collecting reliable data. The plasticized samples help considerably in defining the gray area between 0.19 inch (4.7 mm) and 0.3 inch (7.6 mm), which is gravel but often is classified as fine sediment.

*Embeddedness.* — Embeddedness rates the degree that the larger particles (boulder, rubble, or gravel) are surrounded or covered by fine sediment (table 6). The rating is a measurement of how much of the surface area of the larger size particles is covered by fine sediment (fig. 11). This should allow evaluation of the channel substrate's suitability for spawning, egg incubation, and habitats for aquatic invertebrates, and young overwintering fish. The rearing quality of the instream cover provided by the substrate can be evaluated also. As the percent of embeddedness decreases, the biotic productivity is also thought to decrease.

In our studies, the 95 percent confidence interval around the embeddedness mean was quite low (±5.4 percent), year-to-year precision was rated good, and accuracy was rated fair. Therefore, this is a fairly dependable measurement. The quantitative relationship between this variable and fish health and survival is not well known. Of the streams studied, some had a high fish biomass but low embeddedness rating.

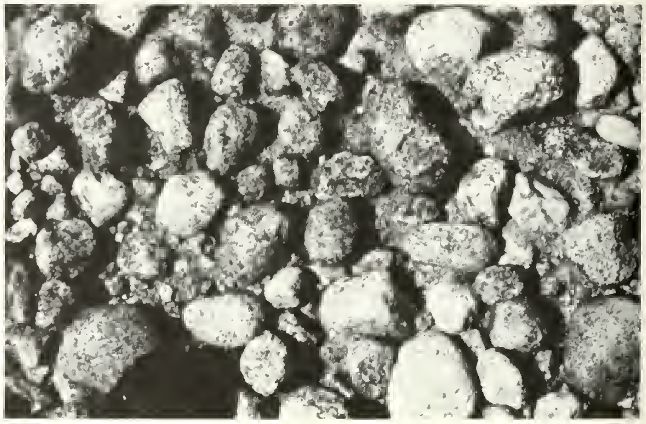

**Figure 11. — A channel embeddedness of 2 because about 20 percent of the perimeter of the rubble-gravel particles are covered by fine sediment.**

Table 6. — Embeddedness rating for channel materials (gravel, rubble, and boulder)

| Rating | Rating description |
|---|---|
| 5 | Gravel, rubble, and boulder particles have less than 5 percent of their surface covered by fine sediment. |
| 4 | Gravel, rubble, and boulder particles have between 5 to 25 percent of their surface covered by fine sediment. |
| 3 | Gravel, rubble, and boulder particles have between 25 and 50 percent of their surface covered by fine sediment. |
| 2 | Gravel, rubble, and boulder particles have between 50 and 75 percent of their surface covered by fine sediment. |
| 1 | Gravel, rubble, and boulder particles have over 75 percent of their surface covered by fine sediment. |

**Figure 12. — Aquatic vegetation dense enough to be classified as instream cover.**

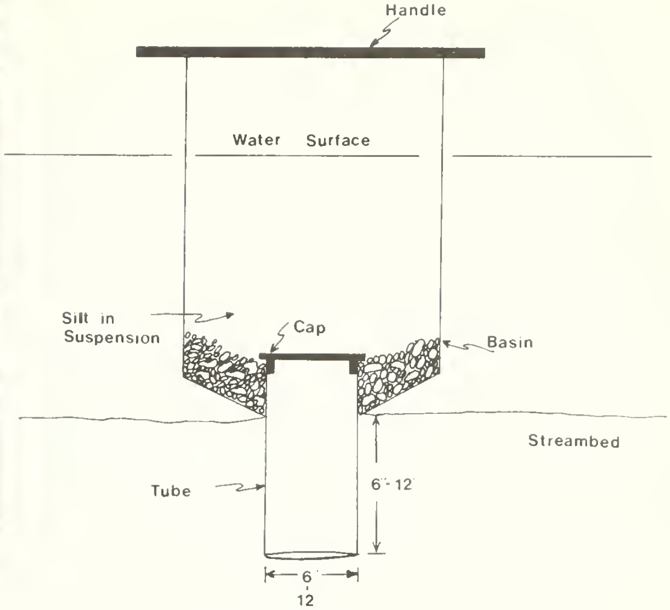


**Figure 13. — Streambed depth material sampler (McNeil) type with completed sample.**

*Channel vegetative cover.* Instream vegetative cover is measured directly along the transect line (fig. 12). Each 1-ft (0.3 m) division of the measuring tape across the transect is evaluated. If more than 50 percent of the foot contains cover, the complete foot is classified as cover. If not, it is ignored. Cover includes algal mats, mosses, rooted aquatic plants, organic debris, downed timber, and brush capable of providing protection for young-of-the-year fish. Thin films of algae on the channel substrate would not be included.

The 95 percent confidence interval around the mean in our studies were wide (±26.2 percent), mainly because of the large natural variation in the cover occurring in the channel. Year-to-year precision and accuracy were rated fair, which means that only major changes in cover condition will be detected by this method. The main problem with this measurement is that it is difficult to get agreement between what will and what will not provide adequate cover for young-of-the-year fish.

**Subsurface analysis.**[3] — Methods for sampling and analyzing the particle size distribution of gravels used by spawning salmonids have evolved slowly during the past 20 years. The first quantitative samplers to receive general use were metal tubes, open at both ends, that were forced into the substrate. Sediments encased by the tubes were removed by hand for analysis. A variety of samplers using this principle have been developed, but one described by McNeil (1964) and McNeil and Ahnell (1964) has become widely accepted for sampling streambed sediments.

More recently, scientists began experimenting with cryogenic devices to obtain sediment samples. These devices, generally referred to as "freeze-core" samplers, consist of a hollow probe driven into the streambed and cooled with a cryogenic medium. After a prescribed time of cooling, the probe and a frozen core of surrounding sediment adhering to it are extracted. Liquid nitrogen, liquid oxygen, solidified carbon dioxide ("dry ice"), liquid carbon dioxide ($CO_2$) and a mixture of acetone, dry ice, and alcohol have been used experimentally as freezing media. Several years of development have produced a reliable sampler (Walkotten 1976) that uses liquid $CO_2$. The freeze-core sampler, like the McNeil core sampler, has become widely accepted for sampling stream substrates.

[3]Contributed by Dr. Fred Everest, Research Fishery Biologist, U.S. Department of Agriculture, Forest Service, Corvallis, Oreg.

*McNeil sampler.* — The McNeil core sampler is usually constructed out of stainless steel and can be modified to fit most sampling situations (fig. 13). The sampler is worked into the channel substrate, and the encased sediment core is dug out by hand and deposited in a built-in basin. When all sediments have been removed to the level of the lip of the core tube, a cap is placed over the tube to prevent water and the collected sediments from escaping when the tube is lifted out of the water. Those suspended sediments in the tube below the cap are lost, but this loss is generally an insignificant percentage of the total sample.

The sediments and water collected are strained through a series of sieves to determine the particle size distribution, percent fines, or geometric mean diameter of the distribution. The sediments collected can be analyzed in the laboratory using the "dry" method or in the field using the "wet" method.

Disadvantages in using the McNeil sampler are that (1) it is limited in particle size diameter to the size the coring tube can trap; (2) it completely mixes the core materials so no interpretation can be made of vertical and horizontal differences in particle size distribution; (3) it is limited to the depth the core can enter the channel substrate, a factor controlled by the water depth, length of the collector's arm, and the depth the core sampler can be pushed into the channel; (4) it is biased if the core tube pushes larger particle sizes out of the collecting area; (5) it allows suspended sediments in the core to be lost; and (6) it cannot be used if the particle sizes are so big or the channel substrate so hard or so cemented that the core cannot be pushed to the required depth.

Regardless of the limitations of this method, when time and money are considered, this is probably the most economical method available to obtain estimates of channel substrate particle size distributions up to 12 inches (305 mm) in channel depth. We recommend the diameter of the McNeil tube to be at least 12 inches (305 mm).

*Freeze-core samplers.* — All of the freeze-core equipment presently available utilizes the same principles, but individual devices may use from one to many probes. The size of sample collected is directly related to the number of probes used and the amount of cryogenic medium used per probe.

Walkotten (1976), Lotspeich and Reid (1980), Everest and others (1980), and Platts and Penton (1980) give discussion on the construction, parts, operations of freeze-core samplers, and analysis of samples collected by the freeze-core method. Platts and Penton (1980) and Ringler (1970) believe that the single probe freeze-core sampler may be biased to the selection of larger size sediment particles.

The accuracy and precision of the single freeze-core and McNeil sampler have been compared in laboratory experiments. Samples collected by both devices were found to be representative of a known sediment mixture, but the freeze-core sampler was more accurate (Walkotten 1976). It is also more versatile, functioning under a wider variety of weather and water conditions, but it too has several disdvantages. It is difficult to drive probes into substrate containing many particles over 10 inches (25 cm) in diameter, and the freeze-core technique is equipment intensive, requiring $CO_2$ bottles, hoses, manifolds, probes, and sample extractors. Also, since it is necessary to subsample cores by depth for accurate interpretation of gravel quality (Everest and others 1980), it is often necessary to collect more massive cores than can be easily obtained by the single-core technique. For example, Adams (1980) used a single-probe device to extensively sample stream substrates in the Oregon coast range. He was able to extract up to six cores of sediment averaging about 3.5 lb per core (1.6 kg/core) per 20-lb tank (9.07-kg) of $CO_2$. Cores of such size are minimal for individual vertical subsampling. Skaugset (1980), on the other hand, was able to obtain cores exceeding 44.1 lb (20 kg) with a single probe device using 10 liters of liquid nitrogen per sample. Skaugset's cores were large enough for representative vertical subsampling, but liquid nitrogen is more expensive and more difficult to obtain, store, and use than liquid $CO_2$.

To alleviate problems caused by the small size of cores obtained by the single-probe sampler using $CO_2$, and to avoid use of liquid nitrogen as a cooling medium, Lotspeich and Reid (1980) and Everest and others (1980) modified the single-probe device. The modified freeze-core sampler uses a triangular array of three probes driven into the substrate through a template, that keeps the probes in a fixed relationship to each other. The "tri-tube" sampler (fig. 14) retains all of the advantages of the single freeze-core sampler, but it extracts larger cores—often more than 44.1 lb per 20-lb (20 kg per 9.1-kg) tank of $CO_2$—which are probably more representative of substrate composition than small cores obtained by the single freeze-core, or cores obtained with McNeil samplers.

We recommend use of the multiprobe procedure if an analysis of horizontal and vertical stratification of sediments is required. We suggest use of the tri-tube sampler described by Lotspeich and Reid (1980) and Everest and others (1980) when numerous cores must be collected, and the sampler described by Platts and Penton (1980) when only a few large cores are needed.

The freeze methods allow collection of eggs and alevins in a redd at any stage of development; the methods will function at most air or water temperatures or stream depths, and will allow analysis of horizontal and vertical locations of eggs and alevins. But, because these techniques require several pieces of equipment, they are most conveniently used in accessible areas.

A major advantage of the freeze-core sampler is that it provides opportunity for vertical stratification of substrate cores. Everest and others (1980) have developed a subsampler that consists of a series of open-topped boxes made of 26-gage galvanized sheet metal (fig. 15). A core is laid horizontally on the boxes of the subsampler and thawed with a blowtorch. Sediments freed from the core drop directly into the boxes below.

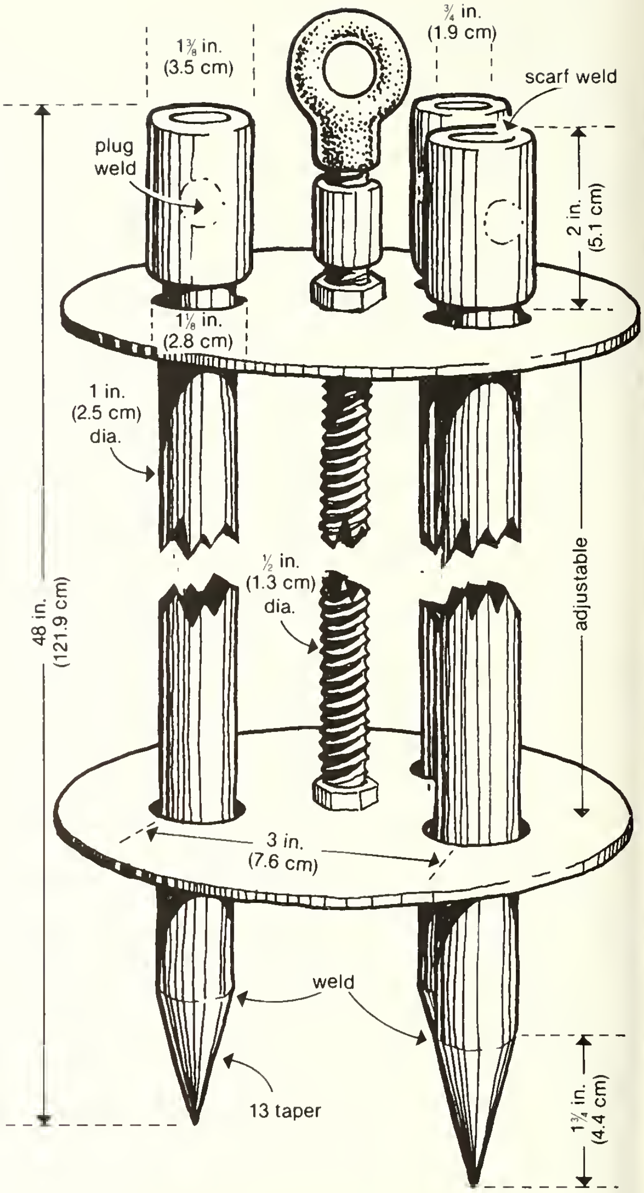


**Figure 14. — Schematic diagram of tri-tube sampler.**

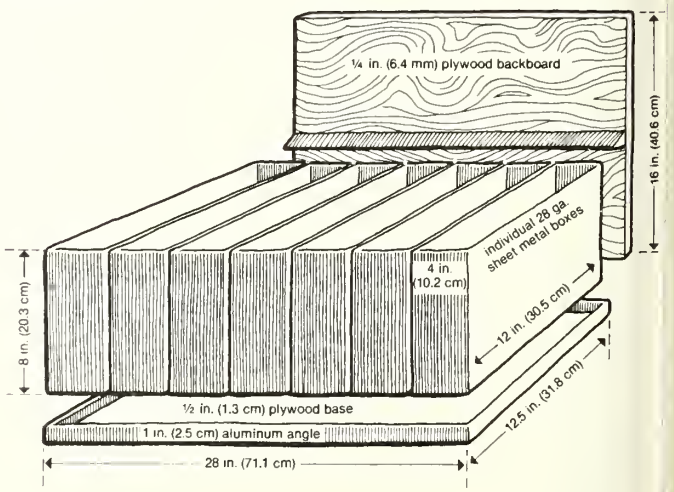


**Figure 15. — Diagram of a freeze-core subsampler.**

*Sampling location and depth.* — Selection of spawning sites by salmonids is a nonrandom activity. Adult salmonids selecting locations to spawn respond to such environmental variables as water depth and velocity, substrate composition, and proximity to cover. Because both sediment particle-size distribution and redd site selection are nonrandom events, the location from which samples are drawn to characterize spawning gravels should be identified by an experienced fishery biologist. Samples should only be drawn from locations that meet the known spawning requirements of a species. The suitability of each sampling site should be determined by quantitative measurements of water depth and velocity. The depth at which the sample is extracted is also critical to the analysis. Samples should be taken only as deep as the average depth of egg deposition for the species being studied. Since there is substantial stratification in stream gravels, sampling above or below the level of egg deposition might yield an inaccurate estimate of the size and distribution of particles within a redd. If prediction of survival to emergence of salmonid fry is desired, all samples should be collected from redds just prior to onset of emergence. Otherwise, temporal variations in gravel composition (Adams and Beschta 1980) might lead to inaccurate assessments of gravel quality at the onset of emergence.

*Sample analysis.* — Sediment samples can be analyzed either in the field or in the laboratory. The "wet method" can be done onsite and is the least expensive, but also the least accurate, method. The wet method usually uses a water-flushing technique with some hand shaking to sort sediments through a series of sieves. The trapped sediment on each sieve is allowed to drain and is poured into a water-filled graduated container. The amount of water displaced determines the volume of the sediment plus the volume of any water retained in pore spaces in the sediment. When the wet method is used, water retained in the sediment must be accounted for, since water retention per unit volume of fine sediments is higher than for coarse sediments. A conversion factor based on particle size and specific gravity can be used to convert wet volume to dry volume. Conversion factors for the normal range of particle sizes and specific gavities are listed in table 7.

For more exacting results, we recommend that the sediment samples be placed in containers and transported to the laboratory for analysis. Laboratory analysis of dry weights is the most accurate because all water in the sample can be evaporated, thus eliminating the need for conversion factors associated with the wet method. In the "laboratory method," the sediment sample is ovendried (24 hours at 221° F [105° C] or airdried, passed through a series of sieves, and that portion caught by each sieve is weighed. We recommend the Wentworth sieve series be adapted to the standard classification on table 4, this includes a progression of five size classes ranging from 0.002 inch to 3.94 inches (0.062 to 100 mm). The upper limit might seem arbitrary, but it approximates the largest size particles in which most salmonids will spawn. Consequently, few grains larger than 5 inches (128 mm) are present in preferred spawning areas. The sixth size class (10.1 to 20.2 inches [256 to 512 mm]) indicates the difficulty salmonids would have in moving the materials to deposit and cover their eggs.

**Table 7.** — Water gained in a wet sieving process and the factor for correcting volumetric data (Shirazi and Seim 1979)

| Sieve size | | Gram water gained gram dry gravel | | | Correction factor applied to wet sieved gravel | | |
|---|---|---|---|---|---|---|---|
| | | [1]$\rho = 2.2$ | $\rho = 2.6$ | $\rho = 2.9$ | $\rho = 2.2$ | $\rho = 2.6$ | $\rho = 2.9$ |
| *Inches* | *mm* | | | | | | |
| 3 | 76.2 | 0.02 | 0.01 | 0.01 | 0.97 | 0.96 | 0.96 |
| | 64 | .02 | .02 | .01 | .96 | .96 | .96 |
| 2 | 50.8 | .02 | .02 | .02 | .96 | .96 | .95 |
| | 32 | .02 | .02 | .02 | .95 | .95 | .94 |
| 1 | 25.4 | .03 | .02 | .02 | .94 | .94 | .94 |
| | 16 | .03 | .03 | .03 | .93 | .93 | .92 |
| 1/2 | 12.7 | .04 | .03 | .03 | .92 | .92 | .91 |
| | 8 | .05 | .04 | .04 | .91 | .90 | .89 |
| 1/4 | 6.35 | .05 | .05 | .05 | .89 | .88 | .88 |
| | 4 | .07 | .06 | .06 | .87 | .86 | .85 |
| 1/8 | 3.18 | .08 | .07 | .07 | .86 | .85 | .84 |
| | 2.0 | .10 | .09 | .08 | .83 | .81 | .81 |
| 1/16 | 1.59 | .11 | .10 | .09 | .81 | .80 | .79 |
| | 1.0 | .13 | .12 | .12 | .77 | .76 | .75 |
| 1/32 | .79 | .15 | .14 | .13 | .75 | .73 | .72 |
| | .50 | .19 | .18 | .17 | .70 | .69 | .67 |
| 1/64 | .40 | .21 | .20 | .19 | .68 | .66 | .65 |
| | .25 | .27 | .25 | .23 | .63 | .61 | .59 |
| 1/128 | .20 | .30 | .28 | .26 | .60 | .58 | .57 |
| | .125 | .38 | .35 | .33 | .54 | .52 | .51 |
| 1/512 | .10 | .43 | .39 | .37 | .52 | .50 | .48 |
| | .063 | .54 | .49 | .47 | .46 | .44 | .42 |

[1]$\rho$ = gravel density.

*Quality indexes.* — The quality of gravels for salmonid reproduction has traditionally been estimated by determining the percentage of fine sediments (less than some specified diameter) in samples collected from spawning areas. The field data can be compared (Hall and Lantz 1969) to results of several laboratory studies (for example, Phillips and others 1975) to estimate survival to emergence of various species of salmonids. While an inverse relationship between percent fines and survival of salmonid fry has been demonstrated by several researchers, beginning with Harrison (1923), use of percent fines alone to estimate gravel quality has a major disadvantage; it ignores the textural composition of the remaining particles that can have a mitigating effect on survival. For example, imagine two samples each containing 20 percent fine sediment less than 1 mm diameter by weight, but the average diameter of larger particles is 10 mm in one sample and 25 mm in the other. Interstitial voids in the smaller diameter material would be more completely filled by a given quantity of fine sediment than voids in the larger material and the subsequent effect on survival of salmonid fry would be very different. Percent fines is a reasonable index to gravel quality, but has serious limitations because it ignores the textural composition of the remainder of the sample.

Other quality indexes have been developed recently in an attempt to improve upon the percent fines method. Platts and others (1979) used the geometric mean diameter ($d_g$) method for evaluating sediment effects on salmonid incubation success. This has advantages over the commonly used percent fines method in that it is a conventional statistical measure used by several disciplines to represent sediment composition; it relates to the permeability and porosity of channel sediments and to embryo survival as well or better than percent fines; and it is estimated from the total sediment composition. But despite these advantages, $d_g$ has been shown by Beschta (in press) to be rather insensitive to charges in stream substrate composition caused by roading in a Washington watershed. Also, Lotspeich and Everest (1981) have shown that use of $d_g$ alone can lead to erroneous conclusions concerning gravel quality. Because of these problems, Beschta (in press) has raised serious questions regarding the utility of the geometric mean diameter as a quality index.

Tappel (1981) offers another approach, which is a modification of the $d_g$ method and uses a linear curve to depict particle size distribution by assigning the points 0.03 inch (0.8 mm) and 0.37 inch (9.5 mm) for determining a line. According to Tappel, the slope of this line gives a truer picture of fine sediment classes detrimental to incubation. A major drawback of this procedure, as with percent fines, is that it ignores the larger particles in a sample and consequently might suffer the same limitations.

A recent spawning substrate quality index that appears to overcome limitations of percent fines and geometric mean has been reported by Lotspeich and Everest (1981). Their procedure uses a measure of the central tendency of the distribution of sediment particle sizes in a sample and the dispersion of particles in relation to the central value to characterize the suitability of gravels for salmonid incubation and emergence. These two parameters are combined to derive a quality index called the "fredle index," which provides an indicator of sediment premeability and pore size. The measure of central tendency used is the geometric mean ($d_g$). Pore size is directly proportional to mean grain size and regulates intragravel water velocity and oxygen transport to incubating salmonid embryos and controls intragravel movement of alevins. These two substrate parameters are the primary legislators of salmonid embryo survival-to-emergence.

The fredle index (f) is calculated by the following method:

$$f = \frac{d_g}{S_o}$$

where:

$d_g = (d_1^{w_1} \times d_2^{w_2} \times \ldots\ldots\ldots d_n^{w_n})$

$d_n$ = midpoint diameter of particles retained on the nth sieve

$w_n$ = decimal fraction by weight of particles retained on the nth sieve

$S_o = \frac{d_{75}}{d_{25}}$ = sorting coefficient

$d_{75}$, $d_{25}$ = particle size diameters at which either 75 or 25 percent of the sample is finer on a weight basis.

Fredle numbers for sediment with a single grain size will be equal to the geometric mean because $S_o$ is then 1. Sediments with the same $d_g$ will have f numbers less than the geometric mean as $S_o$ increases. The examples in figure 16 have a common $d_g$ of 0.47 inch (12 mm) but yield fredle numbers of 12, 3.53, and 1.58, respectively. Sediments with small $d_g$ values are less permeable than those with larger means because pores are small and intragravel flow and movement of alevins is impeded even through $S_o$ might be 1. Also sediments with large $d_g$ might be slowly permeable when $S_o$ is large because pore spaces are occupied with smaller grains that impede interstitial flow and movement. Thus, the magnitude of the fredle index numbers is a measure of both pore size and relative permeability, both of which increase as the index number becomes larger.

The relationship between f values and survival-to-emergence of salmonid alevins has not been documented experimentally. The data of Phillips and others (1975), however, have been used to establish a preliminary relationship between these parameters. Phillips and others (1975) examined survival-to-emergence of coho salmon (*Oncorhynchus kisutch* [Walbaum]) and steelhead trout (*Salmo gairdneri* Richardson) embryos in gravel mixtures of known composition. Calculated fredle numbers for the mixtures of Phillips and others (1975) were plotted against survival (fig. 17). The preliminary relationship indicates that the fredle index is responsive to slight changes in gravel composition, survival, and variations in intragravel habitat requirements of individual species. For example, in Phillips and others (1975) artificial gravels with f of 2, 4, and 8, survival-to-emergence of 30, 60, and 88 percent, respectively, can be predicted for coho salmon, whereas survival of steelhead trout can be predicted at 45, 75, and 99 percent in the same mixtures. The difference between survival of coho salmon and steelhead trout at a given f is probably related to differences in the cranial diameter of alevins, which control their movement through pore spaces in gravel.

This method of calculating a quality index (f) for stream sediments allows biologists and land managers to identify the quality of gravel used for reproduction by anadromous salmonids. Also, comparisons can be made of gravel quality within and between streams, and temporal changes in texture and permeability can be monitored. The technique should be especially useful for measuring changes in gravel quality resulting from sedimentation from nonpoint sources in managed forest watersheds.

### Channel Cross Section Surveys

Surveyed channel cross sections similar to those shown in figures 5 through 7 provide a permanent record of the channel

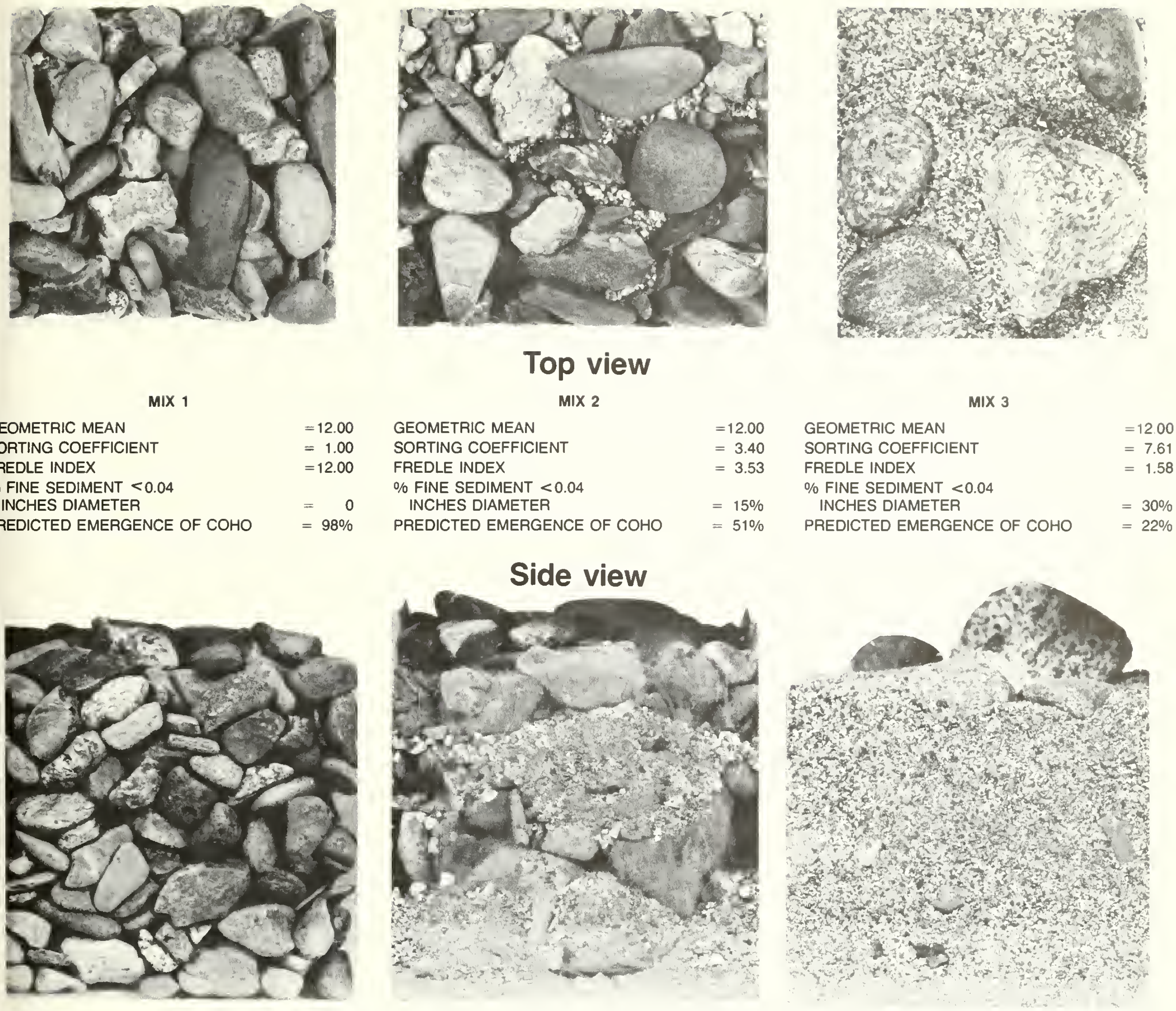


**Figure 16.—Three gravel mixtures with a common geometric mean, but widely divergent distribution of particle sizes.**

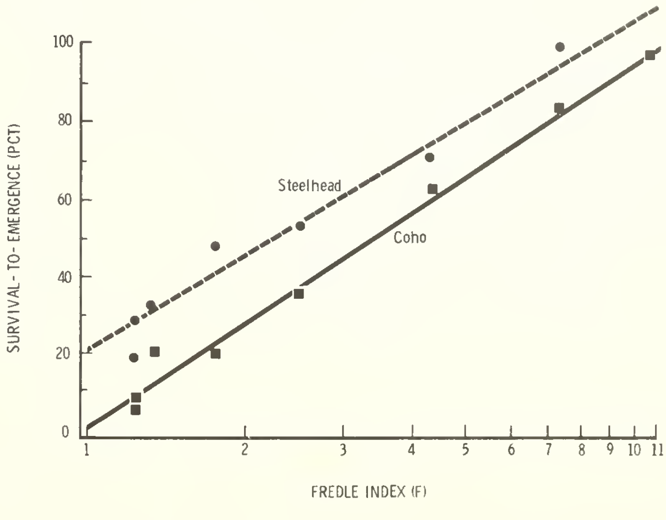


**Figure 17.—Relationship between fredel index (f) numbers and survival-to-emergence of coho salmon and steelhead trout (semilog plot, lines fitted by eye; based on data of Phillips and others, 1975.)**

morphology at any given point in time. Repeated surveys taken at the same locations over time can be used to evaluate time trends in channel bank and bed erosion and deposition. Plotted cross sections are also useful for estimating flow rates for water depths other than those found at the time flow is measured.

Surveys are conducted by stretching a measuring tape across the channel between permanent reference stakes located on the flood plain a safe distance of at least a few feet back from the top of the channel banks depending on bank erosion rates. The tops of the reference stakes, the ends of the tape, the bottom of the reference stakes and all obvious breaks in slope of the surface progressing across the tape are measured using a series of paired horizontal (actually taped distance) and vertical measurements. Care should be taken to measure all profile breaks because straight lines are assumed between measurement points when the data are plotted. Thus, any grade changes not measured will be erased in plotting. Usually, measurements are also made on the top and bottom of the reference stakes in order to simplify the comparison of successive cross sections made at the same location over time (fig. 18). We measure all horizontal and vertical distances to the nearest 0.1 and 0.01 ft (30.5 and 3.0 mm), respectively.

One common procedure for making vertical measurements is to use an engineer's level and level rod using conventional surveying techniques. This procedure requires at least two people, but is precise if done carefully. The channel cross section is plotted by referencing horizontal distances from the end of the tape (we use the right bank for convention) and vertical distance from a bench mark or the height of the instrument for each survey.

Figure 18. — Measuring from the top of the stake to the tension spring handle.

Figure 19. — Measuring from the fencepost to the end of the tension spring.

Another procedure for measuring vertical distances is to simply measure the distance from the tape to the ground surface using a measuring rod. This procedure utilizes the generalized sag tape procedure developed by Ray and Megahan (1979) and can be done by one person if necessary. This is the procedure that we use because it requires fewer person hours, is a little faster, and is precise if proper procedures are followed. Some additional data are required when the sag tape procedure is used including: (1) the difference in elevation between the two ends of the tape; (2) tension applied to the tape (fig. 19); and (3) the weight per foot of the tape.

The difference in elevation between the ends of the tape is determined with an engineer's level and level rod at the time of the first survey. The locations of the tape ends are marked on the reference stakes so that subsequent measurements for cross section surveys are not needed. Tape tension is measured at the time of each cross section survey using a small spring scale attached to the end of the tape. Tape weight is a constant for each tape and is determined by weighing the tape with all brackets or holding devices removed and dividing by the tape length.

Plotting the cross section using the sag tape procedure requires the solution of some ponderous equations. The job is simple, however, if programmed on a computer. The equations and a program flow chart for this generalized sag tape procedure were developed by Ray and Megahan (1979). A program is presently available for use at the USDA Forest Service Computer Center in Fort Collins, Colo., under the name R2-CROSS-81 (Weatherred and others 1981)

### Sedimentation

Sedimentation is a broad term that encompasses two overlapping areas of interest: (1) sediment transport past a channel reference point; and (2) the deposition or erosion of material at a channel reference point. Both aspects of sedimentation are important to the aquatic community.

**Sediment transport.** — Sediment transport is a function of streamflow rate and the rate and size of sediment supply. Sediment transport usually increases logarithmically with streamflow. As a result, the increase in sediment transport for a given increment of flow is much higher for high streamflow rates than for low streamflow rates. Sediment moves either in suspension within the water column as suspended load or by bouncing or rolling along the bottom as bedload. Suspended sediment is most readily apparent to the casual observer and can be deleterious to fish if sediment concentrations are high enough for a long enough period. However, bedload may be more damaging because of loss of food supplies and spawning habitat and changes in channel morphology.

Evaluation of sediment transport goes beyond the scope of most aquatic environment studies and will not be discussed in detail here. This is primarily because determination of sediment transport must be made throughout the flow hydrograph. An isolated sediment transport measurement made during the low flow period required for most aquatic environment studies would be meaningless. Guidelines for collecting suspended sediment data are available in "Field Methods for Measurement of Fluvial Sediment" (Guy and Norman 1970) and by consultation with sedimentation specialists and hydrologists.

Techniques for bedload sediment measurement have not been standardized. The closest thing to a standard sampler is the Helley-Smith sampler (Helley and Smith 1971). Subsequent calibration by Emmett (1979) shows that the sampler has merit for most applications.

Platts, William S.; Megahan, Walter F.; Minshall, G. Wayne. Methods for evaluating stream, riparian, and biotic conditions. Gen. Tech. Rep. INT-138. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 70 p.

ERRATA

Page 16 Figure 11, first line
A channel embeddedness of 4 instead of 2.

Page 23 Line 13, 1st column
Elevation instead of evaluation

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Page 25 Figure 20
Photograph is upside down

Page 30 Equation 7
Eliminate the last parenthesis

Page 31 Equation 17
The first and last brackets in the denominator are backwards

Page 32 Line 52, 1st Column
28.3 instead of 20.3

Page 33 Table 12, line 2
6-10 instead of <6-10

Page 57 First equation should be

$$\overline{D} = \frac{A}{W} = \frac{\sum_{i=1}^{4} \left(\frac{D_i + D_{i+1}}{2}\right)\left(\frac{W}{4}\right)}{W} = \sum_{i=1}^{4} \frac{D_i + D_{i+1}}{8}$$

Laboratory analysis of sediment samples has also been standardized. Guy (1973) describes laboratory methods for analysis of both suspended and bedload samples for concentration, particle size distribution, and other properties of concern, such as percent organic matter.

**Erosion and deposition.** — Studies of erosion and deposition of materials at a given channel point are more relevant for aquatic environment studies than measurements of sediment transport past a given point. Evaluation of erosion or deposition of bottom materials requires successive (usually annual) measurements to be taken at low flow periods. Such measurements are easily included in aquatic habitat studies. Erosion or deposition are documented by changes in the evaluation of the bottom and in the particle size distribution of bottom materials. A number of techniques are available including surveyed cross sections, painted rocks, buried chains, streambed surface particle size evaluation, and particle size analysis of streambed cores. Megahan and others (1980) report on a study using many of these techniques to evaluate trends in channel conditions in the South Fork of the Salmon River over a 15-year period.

The best method for quantifying the volume of channel erosion and deposition is with the use of successive channel cross sections. A comparison of cross sections using the same data illustrates the amount and location of bed elevation changes. Sometimes no changes in bottom elevation are detected by successive cross sections taken during low flow periods, even though considerable erosion or deposition occurs during high flows. Channel cross sections taken at high and low flow levels are needed in such situations. However, frequent cross section surveys can be impractical and oftentimes downright dangerous, especially during high flows.

Painted rocks can be used to evaluate the amount of disturbance of surface bed materials during high flows. Various sized sediment particles are removed from the surface of the channel bottom and painted a brilliant color and then replaced at known locations on the streambed. Placement must be done carefully so that the painted rocks are fitted into the streambed surface similar to the undisturbed bed particles. A susequent comparison of the location of painted sediment particles provides an indication of the size of bedload particles moved during the intervening high flow period.

Painted rocks give an indication of the size of materials moved on the streambed surface but do not show the depth of erosion and subsequent deposition. The method of buried chains provides a means of doing this. A driving ring is attached to the end of a small gage chain. The ring is placed over the pointed end of a metal driving rod and the rod and chain are driven vertically to the desired depth. By twisting and tamping the driving rod during removal, the bed sediments are packed around the chain, leaving it suspended vertically in the bottom sediments. When bed scour occurs, the free upper end of the chain collapses or is bent from the vertical and swept downstream. Subsequent fill is deposited on top of the horizontal segment of chain. After high flow, the chain is relocated by survey and dug out. The position of the bend indicates the depth of scour and redeposition.

In some situations, the amount of scour and fill on the stream bottom is not as critical as is the change in particle size distribution of the bottom. This is especially true in salmon and steelhead spawning areas where increases in the percentages of fine sediment can severely reduce fry survival (Bjornn 1973; Phillips and others 1975).

### Channel Debris and Sediment Storage

Debris in streams is often considered harmful because log jams can create physical blocks to migrating fish. In addition, excessive inputs of small debris, such as leaves and small branches, can reduce oxygen levels in the water under certain conditions (Narver 1971). However, it is well to bear in mind that organic debris, consisting of logs, branches, and leaves, is a natural and necessary component of forest aquatic ecosystems. The food base for the biological community of forest streams is mostly woody debris and leaves. Wood in streams also serves as a substrate for biological activity and creates other habitat niches by regulating the movement of water and sediment.

Debris loading can be influenced by forest management activities; loading may increase if logging debris is added to the channel or it may decrease if channel clearing takes place. Vegetation removal in the immediate vicinity of the channel also reduces debris loading in the long run by reducing the inflow of debris from natural mortality.

There has been increasing research in recent years to evaluate the role of debris in channels, including methods to inventory debris and its effects on channel sediment storage. Froelich (1973) describes a method for quantifying the volume of debris storage in channels. Swanson and Lienkaemper (1979) developed techniques to study the frequency of occurrence of wood and wood-created habitat in undisturbed forest streams in Oregon. They found that wood or wood-created habitat comprised 50 percent of the total stream area on first-order streams and 25 percent of the total stream area on third-order streams. Our research has been devoted to evaluating the volume of sediment storage behind channel obstructions because of biological implications and the need to develop monitoring techniques for accelerated sediment production from forest management activities. Megahan and Nowlin (1976) showed that, on the average, over 10 times more sediment was stored behind debris in seven study channels than was deposited in sediment basins at the mouth of the streams each year.

We use a sampling system to inventory sediment accumulations behind natural channel obstructions, including woody debris on headwater streams. Sample reaches 140 ft (42.7 m) in length are located at 360-ft (109.7-m) intervals starting at the mouth of the drainage and progressing upstream along the dominant channel until the point is reached where there are no obvious indications of flow. Obstructions are defined as any material in the channel causing sediment accumulations because of discontinuities in channel gradient and include: logs (more than 4 inches [10 cm] in diameter), rocks, roots, stumps; and other debris (includes branches, twigs, and leaves).

Sampling is restricted to obstructions causing sediment accumulations with the following minimum dimensions: height 0.66 ft (0.2 m); averge width 0.98 ft (0.3 m); and length 1.97 ft (0.6 m). Eliminating the smaller obstructions greatly reduces the work and causes a loss of only about 10 percent of the total volume of stored sediment. Height (H) is defined as the difference between a stadia rod reading taken on the bed at the downstream side of the obstruction (the rod is raised if necessary to correct for any scouring at this point) and a rod reading taken on the sediment deposit immediately upstream from the obstruction. Rod readings are taken to the nearest 0.01 ft (0.4 cm) using an abney level. Length (L) is the distance from the upstream end of the obstruction to the upstream end of the accumulated sediment. Width (W) of the sediment accumulation is the average of three widths taken normal to the length at distances of 0.16, 0.5, and 0.83 of the length from the obstruction. The upstream end and edges of sediment accumulations are defined by breaks in channel gradient, differences in the particle size distribution of bottom sediments, and differences in composition of bottom materials.

Total volume (V) of sediment stored behind the obstruction is calculated assuming a triangular wedge of sediment as:

$$V = \frac{H}{2} LW.$$

A third rod reading is taken at the upstream end of the obstruction to allow calculation of the slope of the accumulated sediments. The most apparent cause of the obstruction is defined by type as logs over 25 inches (63.5 cm) in diameter, rocks, roots, stumps, and organic debris (the last includes branches less than 25 inches diameter, twigs and leaves).

**Stream Order**

Stream order is defined by Horton (1945) and Langbein and Iseri (1960) by means of a method of numbering streams as part of a drainage basin network. Tributaries that have no branches are designated first-order streams; those that receive only first-order streams are second-order streams; larger branches that receive only first-order and second-order tributaries are designated third-order streams, and so on. Stream order provides a useful indicator of the physical and biological characteristics of streams (Lotrich 1973; Whiteside and McNatt 1972; Platts 1979).

We recommend that for stream order to provide high utility for interpretations, the first-order channels should be identified by direct inspection. In lieu of this, first-order streams are defined as the first channel formed in the headwaters that can be identified on USGS 7½-minute quadrangle maps. The largest available USGS map scale should be used if 7½-minute maps are not available for the area in question. Care should be used when comparing stream order in different geologic settings. The use of stream order, especially for planning purposes, can help compensate for lack of money or manpower by providing general information on fish species present, fish standing crops, stream width, stream depth, and channel substate composition (Platts 1979). However, we do not recommend using stream order alone if high resolution is needed.

# RIPARIAN ZONE

The riparian ecosystem includes the streambank and the flood plain and is defined for this report as the vegetation portion of the streamside environment. Many land uses effect this part of the stream habitat. Riparian vegetation helps stabilize the streambanks, provides cover and food for fish, and intercepts solar radiation.

## Streamside Cover

This rating considers all material (organic and inorganic) on or above the streambank that offers streambank protection from erosion and stream shading, and provides escape cover or resting security for fish:

| Rating | Description |
|---|---|
| 4 | The dominant vegetation is shrub. |
| 3 | The dominant vegetation influencing the streamside and/or water environment is of tree form. |
| 2 | The dominant vegetation is grass or forbs. |
| 1 | Over 50 percent of the streambank transect line intercept has no vegetation and the dominant material is soil, rock, bridge materials, road materials, culverts, and mine tailings. |

The area of streambank rated is that intercepted by the transect line that covers the exposed stream bottom, bank, and top of bank.

Initially in determining this rating, all vegetation along the stream that would reach the stream (if it were laid down towards the stream) was used in the analysis. This procedure caused high observer variation and increased confidence intervals. Therefore, we revised it to include only that cover intercepted by the transect line. This decreased the observer error and confidence intervals. The higher level offsite vegetation not considered must therefore be accounted for with some type of canopy rating.

In some rating systems (Forest Service Region 4 Methodology) used by fishery biologists, tree cover is given a higher environmental rating than shrubs. We found that streams bordered by brush had a higher fish standing crop than similar sized streams with tree borders (Platts 1974). Therefore, this manual rates brush cover higher than tree cover.

The cover rating is effective in evaluating the effects of such activities as channelization, logging, or cattle grazing on riparian habitat. This measurement in our studies had low confidence intervals about the mean (±4.1 percent) mainly because dominant cover tends to be uniform and observers evaluate the same conditions alike even though they may not rate it correctly. Year-to-year precision and accuracy were poor and demonstrate that problems can occur using this measurement.

## Vegetation Use by Animals

Vegetation use under the transect line within 5 ft of the shoreline is rated visually. This evaluation considers vegetation disturbed during the present growing season and potential plant growth that does not exist because of past disturbance. An example of loss because of past use would be in areas where vegetation no longer exists because the streambank was dredged, trampled, or eliminated by a major cattle crossing. The rating, however, applies mainly to recent vegetation use. If use is determined on only one occasion or only one time a year, it should be done as soon as possible after the land use effect and before plant regrowth can occur.

The vegetation use rating is stratified into four classes:

| Rating (percent) | Description |
|---|---|
| 0 to 25 (Light) | Vegetation use is very light or none at all. Almost all the potential plant biomass at present stage of development remains. The vegetative cover is very close to that which would occur naturally without use. If bare areas exist, (i.e., bedrock) they are not because of loss of vegetation from past grazing use. |
| 26 to 50 (Moderate) | Vegetative use is moderate and at least one-half of the potential plant biomass remains. Average plant stubble height is greater than half of its potential height at its present stage of development. Plant biomass no longer on site because of past grazing is considered as vegetation that has been used. |
| 51 to 75 (High) | Vegetative use is high and less than half of the potential plant biomass remains. Plant stubble height averages over 2 inches. Plant biomass no longer on site because of past grazing is considered as vegetation that has been used. |

| | |
|---|---|
| 76 to 100 (Very high) | Use of the streamside vegetation is very high. Vegetation has been removed to 2 inches or less in average stubble height. Almost all of the potential vegetative biomass has been used. Only the root system and part of the stem remain. That potential plant biomass that is now non-existent because of past elimination by grazing is considered as vegetation that has been used. |

Once the observer has decided the class, then the actual percentage use is determined. For example, if the vegetation (grasses and forbs) has been reduced to less than 2 inches (50.8 mm) stubble standing height, the class rating is between 76 and 100 percent. If the vegetation is almost to ground level, the final intraclass rating would be 100 percent. If the vegetation is slightly less than 2 inches (50.8 mm) stubble height and there are no areas without vegetation from past livestock use, then the intraclass rating would be about 76 percent.

In our studies, the 95 percent confidence intervals about the means (±12 percent) are high, but still within acceptable limits for most streams studied. Precision and accuracy are good. The observer should be well trained and have ungrazed plots for constant comparison. Our visual estimates of vegetation use were quite close to use estimates gained with actual measurements with the Neal herbage meter (table 8).

**Table 8.** — Comparison of streamside herbage use using the Neal herbage meter versus the visual method

| | 1979 | | | 1980 | | |
|---|---|---|---|---|---|---|
| Study area | Meter | Visual | Δ% | Meter | Visual | Δ% |
| Idaho (10 streams) | 45 | 44 | 1 | 58 | 60 | 2 |
| Nevada (2 streams) | 81 | 68 | 13 | 63 | 57 | 6 |
| Utah (1 stream) | 84 | 76 | 8 | 104 | 87 | 17 |

## Herbage Production and Utilization

Herbage production and utilization were measured in a nondestructive method using a Neal Model 18-2000 electronic capacitance meter that measures the conductivity of materials within its field. The measurement generated by the meter is a unitless number that is linearly related to the mass of the measured material. As a result, clipped vegetation weights for selected plots can be graphed against their respective meter readings to generate a regression equation and curve from which further weights can be estimated directly from meter readings without the need to weigh each sample. To plot the regression line, at least 12 plots similar to the vegetation being sampled must be clipped and weighed. The regression equation also can be used to determine vegetative production for the study area, and a comparison of grazed and ungrazed sites provides a vegetation use estimate by simple mathematical manipulation as follows:

1. 1 g per 2 $ft^2$ = 48 lb/acre

where meter reading estimates grams per 2 $ft^2$.

2. Production in the ungrazed area in pounds per acre is:

$$P_u = 48 \left[ \frac{\sum_{u=1}^{n} (a + bx_u)}{n} \right]$$

where:

$P_u$ = production in the ungrazed pasture

and

$x_u$ = meter readings in the ungrazed pasture

a = y intercept

b = regression coefficient

n = number of primary sample plots

3. Production in the grazed area in pounds per acre is:

$$P_g = 48 \left[ \frac{\sum_{g=1}^{n} (a + bx_g)}{n} \right]$$

where:

$P_g$ = production in the grazed pasture in pounds per acre

and

$x_g$ = meter readings in the grazed pasture.

4. Percent vegetative use = $\left[1 - \left(\frac{P_u}{P_g}\right)\right]$ (100).

A brief description of operating procedures and field methodology is found in Neal and others (1976). Herbage meter measurements should be taken on ungrazed and grazed areas concurrently and immediately after the grazing season. We found the meter to be very accurate with regression curves that had $R^2$ values consistently greater than 0.85.

## Vegetation Overhang

Vegetation overhang indirectly provides fish food and cover and shades the water from solar radiation (fig. 20). Overhang is a valuable variable to use in evaluating those land use effects such as logging and road construction that could alter the riparian habitat. Streamside cover rates all vegetation. Vegetation overhang rates only that vegetation overhanging the water column.

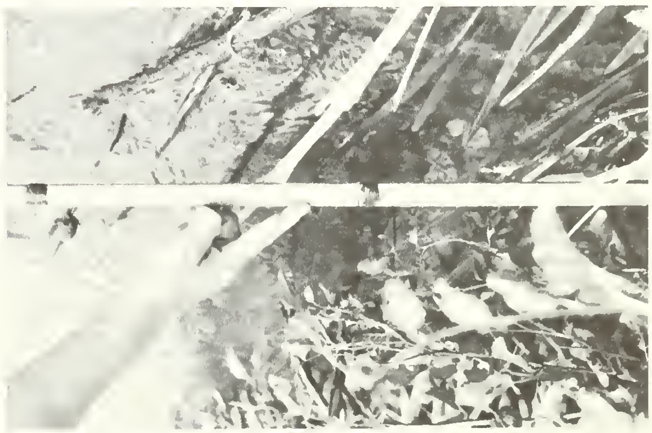


**Figure 20. — Measuring overhanging streamside vegetation.**

This is a direct measurement to the nearest 0.1 ft (0.03 m) of the vegetation (excluding tree trunks or downed logs) within 12 inches (304.8 mm) of the water surface and overhanging the water column (fig. 21).

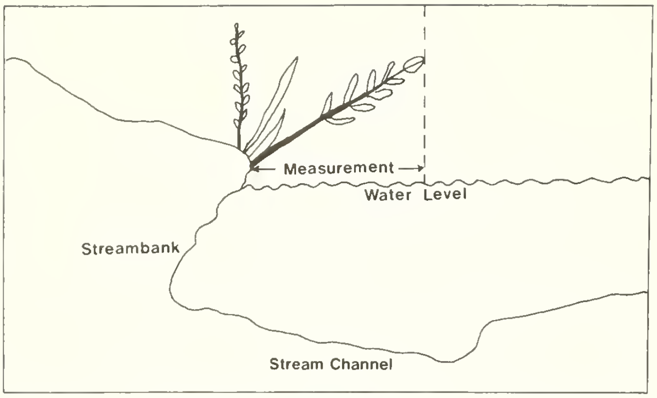



**Figure 21. — Measurement of overhanging vegetation.**

The measurement is taken along the transect line, beginning at the farthest protrusion of the streambank over the water surface, to the farthest point that vegetation covers the water column. This measurement does not include the undercut; therefore, the two measurements combined, give the total overhead cover.

In our studies the 95 percent confidence intervals around the means (±15.7 percent) are fairly wide, but year-to-year precision and accuracy rate fair.

## Habitat Type

The streamside environment consists of many types of habitats and it is often theorized that the type and diversity can determine fish productivity. The habitat type evaluates only the channel-streambank area intercepted by the transect within 10 ft (3.05 m) of the stream shore. This rating is an evaluation of the dominant and subdominant material (organic or inorganic) composing the surface or overstory of the streamside environment. Combinations of plant and soil usually make up this environment, but occasionally a single material, such as sand or log, will describe the habitat type.

This rating was designed with the assumption that streamside environments composed of fine sediments (sand) have less value to fish than brush-sod environments, which have the highest value. All other habitat types fall between these two extremes (table 9). All existing cover is considered, but only the dominant and subdominant materials are selected for the final classification. The subdominant type would be the second most abundant material.

The year-to-year precision was excellent, but the accuracy ratings were only fair. Confidence intervals around the means in our studies (±4.9 percent) are low so the attribute has some possibilities. Over time, this measurement will determine changes in vegetation species as well as habitat type (such as a streamside environment that changes from brush-sod to fine-grass under an improper grazing situation).

# FISH POPULATION EVALUATION

Fish populations are a result of the physical, biological, and chemical factors surrounding them and especially those biotic factors in the trophic levels below them. To sample all the trophic levels is not only expensive but often impossible; however, because fish are dependent on these lower levels, much understanding of ecosystem functioning can be gained from the fish themselves. The environmental tolerances and competitive interactions of fish are generally quite well known. The size, structure, and growth rates of the population allow determination of aquatic habitat conditions that existed in the past 2 to 10 years. Because year class strength is usually set during the early life-history stages, it allows us to follow several years of known conditions to determine reactions of fish to these conditions. Also, the results of the analysis can be related directly to the congressional mandate (Water Quality Act of 1972) of "fishable waters."

Sampling of fish populations must be done accurately because freshwater fish are notorious for wide fluctuations in year-class strengths. Use of electrofishing, explosive primacord, spot explosive concussion, toxicants, nets, scuba or snorkle, and redd counts are common field techniques to obtain data with which to estimate fish population numbers and biomass, fish species composition, and fish health and survival. Each technique has advantages and disadvantages that must be considered in the final selection of the method chosen to obtain the data.

## Electrofishing

Electrofishing is an efficient capture method that can be used to obtain reliable population estimates, length-weight relationships, and age and growth on most streams of order 6 or less. Electrofishers tend to collect larger fish more easily than smaller fish, but the newer electrical transformers now available allow adjustable control of voltage, pulse, and electrical frequency thereby reducing size selectivity. Electrofishing efficiency can also be affected by stream conductivity, temperature, depth, and clarity of water. Each condition must be considered to ensure a reliable population estimate. Electrofishing can be more efficient than other methods of population estimates, such as seining and underwater observation. Boulder-rubble substrate, turbidity, aquatic vegetation, and undercut banks can bias other population estimation methods.

Using the newer electrofishers and successive removal-depletion techniques, we adequately sampled fish in streams up to stream order 5, even in infertile water (less than 35 mg/liter total dissolved solids). The removal-depletion method of population analysis (Zippin 1958) assumes that:

1. No animal can move in or out of the sample area;
2. Each animal has an equal chance of being captured;
3. The probability of capture is constant over all removal occasions.

These assumptions can be approached on small streams of order 5 or less if (1) pulse, frequency, and voltage are applied to reduce selectivity; (2) the sample area has fish passage blocks to keep fish from leaving the area; (3) a consistent proportion of the population is captured during each electrofishing pass; and (4) timing devices on the electrofishers are used to make sure capture effort is the same on all removals.

During electrofishing fish tend to swim or drift downstream; so it is imperative that the downstream blocking net be in place. Sometimes the upstream end of the sample area can be located at a fish passage restriction area. If this restriction is not available, then another blocking net is needed. We found that small salmonids less than 6 inches (152.4 mm) in length seldom tried to leave the area, but large salmonids would attempt to escape. A constant capture probability was difficult to obtain when sampling sculpin populations because of their tendency to remain in the substrate.

### Two-Step Method

During 1975 and 1976, we used the two-step removal method (Seber and LeCren 1967) because it required only two passes with the electrofisher. Population estimates are easily derived with the simple formula:

**Table 9.** — Streamside habitat type rating

| Rating | Streambank material | | Rating | Streambank material | |
|---|---|---|---|---|---|
| | Dominant | Subdominant | | Dominant | Subdominant |
| 1 | [1]All fines | | 13 | Boulder | Root |
| 2 | Fines | Gravel | 13 | Boulder | Tree |
| 2 | Fines | Grass | 13 | Boulder | Sod |
| 2 | Fines | Rubble | 13 | Boulder | Brush |
| 3 | Fines | Boulder | 12 | Root | Fines |
| 3 | Fines | [2]Root | 13 | Root | Gravel |
| 3 | Fines | [3]Tree | 12 | Root | Grass |
| 3 | Fines | [4]Sod | 13 | Root | Rubble |
| 3 | Fines | Brush | 13 | Root | Boulder |
| 4 | Gravel | Fines | 13 | All root | |
| 5 | All gravel | | 14 | Root | Tree |
| 6 | Gravel | Grass | 13 | Root | Sod |
| 6 | Gravel | Rubble | 14 | Root | Brush |
| 7 | Gravel | Boulder | 12 | Tree | Fines |
| 8 | Gravel | Root | 13 | Tree | Gravel |
| 8 | Gravel | Tree | 13 | Tree | Grass |
| 7 | Gravel | Sod | 13 | Tree | Rubble |
| 8 | Gravel | Brush | 13 | Tree | Boulder |
| 8 | Grass | Fines | 14 | Tree | Root |
| 9 | Grass | Gravel | 14 | All tree | |
| 9 | All grass | | 14 | Tree | Sod |
| 9 | Grass | Rubble | 14 | Tree | Brush |
| 9 | Grass | Boulder | 12 | Sod | Fines |
| 11 | Grass | Root | 13 | Sod | Gravel |
| 12 | Grass | Tree | 14 | Sod | Grass |
| 13 | Grass | Sod | 15 | Sod | Rubble |
| 17 | Grass | Brush | 16 | Sod | Boulder |
| 8 | Rubble | Fines | 18 | Sod | Root |
| 9 | Rubble | Gravel | 18 | Sod | Tree |
| 9 | Rubble | Grass | 17 | All sod | |
| 10 | All rubble | | 19 | Sod | Brush |
| 10 | Rubble | Boulder | 17 | Brush | Fines |
| 11 | Rubble | Root | 20 | Brush | Gravel |
| 11 | Rubble | Tree | 20 | Brush | Grass |
| 11 | Rubble | Sod | 21 | Brush | Rubble |
| 12 | Rubble | Brush | 22 | Brush | Boulder |
| 11 | Boulder | Fines | 23 | Brush | Root |
| 12 | Boulder | Gravel | 23 | Brush | Tree |
| 12 | Boulder | Grass | 24 | Brush | Sod |
| 12 | Boulder | Rubble | 23 | All brush | |
| 12 | All boulder | | | | |

[1]Fines include sands, silts, clays, and organic fine particle materials.
[2]Includes only roots from brush and trees.
[3]Downfall logs included.
[4]Sod has an extensive root mass and is more stable than grass or grass tufts.

$$\hat{N} = \frac{(U_1)^2}{(U_1 + U_2)} \qquad (1)$$

here:

$\hat{N}$ = the fish population estimate
$U_1$ = the number of fish collected in first removal
$U_2$ = the number of fish collected in second removal.

The standard error of the estimate can be calculated using:

$$SE(\hat{N}) = \sqrt{\frac{(U_1)^2 \times (U_2)^2 \times T}{(U_1 - U_2)^4}} \qquad (2)$$

where:

$SE(\hat{N})$ = standard error of the population estimate
T = the total number of fish collected $(U_1 + U_2)$.

To illustrate, assume that 400 fish were collected in the first removal and 350 in the second. The population estimate is:

$$\hat{N} = \frac{(400)^2}{(400-350)} = 3{,}200$$

and the standard error is:

$$SE(\hat{N}) = \sqrt{\frac{(400)^2 \times (350)^2 \times 750}{(50)^4}} = 1{,}533.62.$$

In this example, almost as many fish were collected in the second removal as in the first. The two-step method may not give estimates with narrow enough confidence intervals to determine whether fish standing crops were actually changing over time. Other depletion models are available that allow for two or more removals and provide better population estimates with narrower confidence intervals (table 10).

## Zippin Method

From 1977 to 1981, we used two analyses with the multiple-step removal-depletion method: the Zippin 1958 method, based on Moran's (1951) work, and Burnham's maximum likelihood. After experimenting with two-, three-, four-, five-, and six-step removals, we felt, when time and money are considered, the four-step method is the most efficient. Using the Zippin approach with four removals, we narrowed the confidence intervals around the population estimate, and we could begin to determine whether small changes in the fish population over time were significant. The computer program (FPSP-AI) for calculating population estimates using this likelihood method is given in its entirety in appendix 6. The Zippin method is based on a maximum likelihood model (Moran 1951) which has the probabilities reduced to easily used graphs.

The first quantity required is:

$$T = \sum_{i=1}^{k} U_i \; (T = U_1 + U_2 + \ldots + U_k) \qquad (3)$$

where:

T = total number of fish collected

$U_i$ = number of fish collected in the ith removal

k = the number of removals.

In the previous example, 400 fish were removed in step 1 and 350 fish in step 2. Using the Zippin method with four passes (k=4), assume 100 fish were removed in step 3 and 50 fish in step 4. Then:

$$T = 400 + 350 + 100 + 50 = 900.$$

Next the ratio (R) must be determined from the following formula:

$$R = \frac{\sum_{i=1}^{k} (i-1)\,U_i}{T} = \frac{(1\text{-}1)U_1 + (2\text{-}1)U_2 + \ldots + (k\text{-}1)U_k}{T} . \qquad (4)$$

In our example:

$$R = \frac{U_2 + 2U_3 + 3U_4}{T}$$

$$R = \frac{350 + 200 + 150}{900} = 0.78 .$$

Figure 22 must be used to find the proportion $(\hat{Q})^4$ of fish captured during all removals that correspond to the value for R.

The population estimate is then determined by:

$$N = \frac{T}{\hat{Q}} . \qquad (5)$$

where:

$\hat{Q}$ = the proportion of the fish captured during all removals and is determined from figure 22. The ratio R = (0.78) is used to find the point on the curve that corresponds to the $\hat{Q}$ value. In this case, $\hat{Q}$ = 0.92.

Therefore in our example:

$$\hat{N} = \frac{T}{\hat{Q}} = \frac{900}{0.92} = 978 \text{ fish.}$$

[4]This proportion is deonated $(1\text{-}\hat{q}^k)$ in Zippin (1958) and its mathematical derivation is described in that publication.

Table 10. — An example of 95 percent population confidence intervals achieved with the two-step and multiple-step methods in the same stream reach on the South Fork Salmon River on a bull trout (*Salvelinus confluentus* Suckley) population

| Year | Population estimate | Standard error | ±95 percent confidence interval | Method |
|---|---|---|---|---|
| 1975 | 405 | 31.1 | 61 | two-step |
| 1976 | 271 | 85.9 | 168 | two-step |
| 1977 | 808 | 8.4 | 17 | four-step |
| 1978 | 323 | 4.4 | 9 | four-step |
| 1979 | 1,511 | 17.2 | 34 | four-step |
| 1980 | 682 | 13.7 | 27 | four-step |
| 1981 | 386 | 11.9 | 23 | four-step |

The accuracy of a population estimate is largely determined by how closely the underlying assumptions of the removal-depletion method were followed. To measure the reliability of the population estimate, it may be useful to calculate confidence intervals. Confidence intervals enable one to state with given probability the population estimate within a certain range. Assuming that we have a normal frequency distribution, the chance that the true population differs from the population estimate by more than 1.96 standard errors above and below the population estimate is less than 1 in 20. For our work, we assume a normal frequency distribution, which may not be the case with small sample sizes.

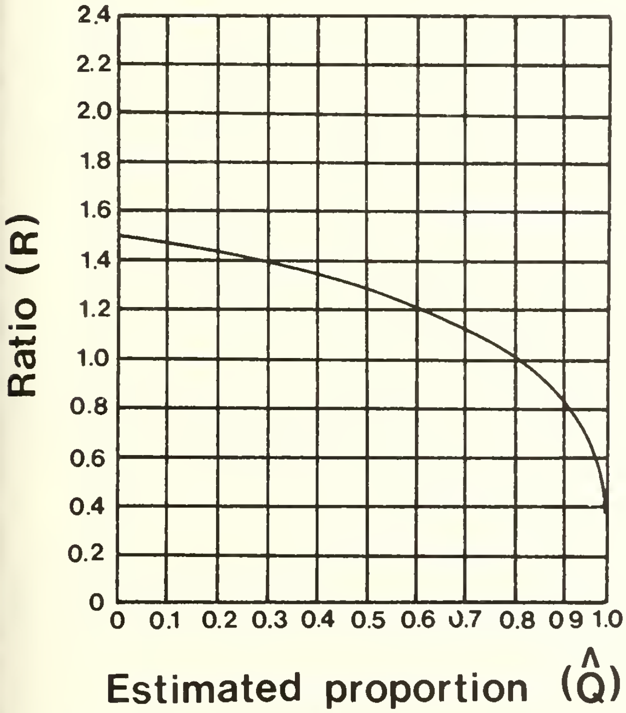



**Figure 22. — Graph used to determine the estimated proportion ($\hat{Q}$) of fish captured during all removals from the ratio (R) of the sum of the products of the number of fish captured during each successive removal and the number of the preceeding removal to the total number of fish collected.**

The formula for the standard error using the Zippin method is:

$$SE(\hat{N}) = \sqrt{\frac{\hat{N}(\hat{N}-T)T}{T^2-\hat{N}(\hat{N}-T)\frac{(k\hat{P})^2}{1-\hat{P}}}} \quad (6)$$

where:

$\hat{P}$ = the estimated probability of capture during a single removal and is obtained from the graph in figure 23.

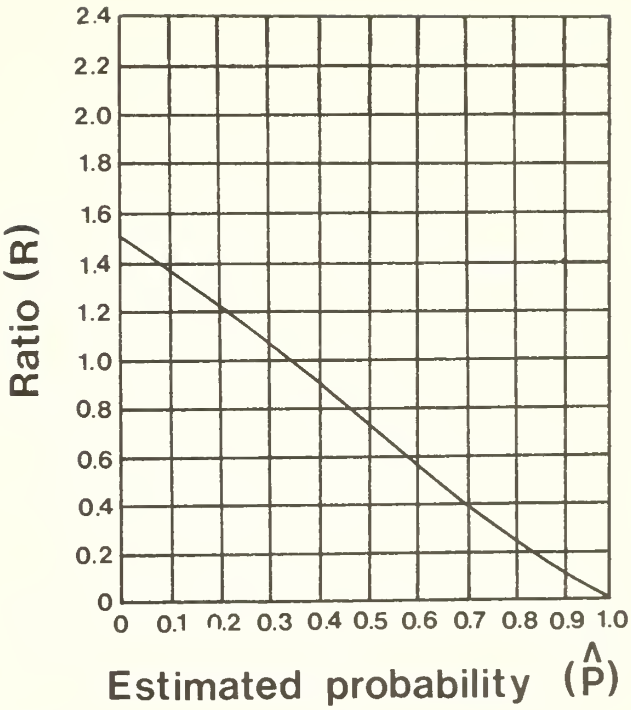



**Figure 23. — Graph used to determine the estimated probability ($\hat{P}$) of capture during a single removal from the ratio (R) of the sum of the products of the number of fish captured during each successive removal and the number of the preceeding removal to the total number of fish collected.**

The standard error from our example using four removals is:

$$SE(\hat{N}) = \sqrt{\frac{(978)\ (978\text{-}900)\ (900)}{(900)^2\text{-}(978)\ (978\text{-}900)\left[\frac{(4\times0.47)^2}{(1\text{-}0.47)}\right]}}$$

$$= \sqrt{227.87} = 15.10.$$

The confidence interval is calculated by taking the population estimate plus and minus 1.96 times the standard error of the population estimate. The population estimate 978 ± 1.96 × 15.90 equals 978 ± 29.6, which equals 948 and 1,008. The third and fourth removals helped narrow the 95 percent confidence interval from 750 to 6,267 using the Seber-LeCren two-step method to 948 and 1,008 using the Zippin method with four removals. Generally speaking, the higher the number of removals, the narrower the confidence interval.

A chi-square test ($\chi^2$) can be used to determine the goodness of fit between our actual removal pattern with its varying capture probabilities and a theoretical removal pattern that assumes a constant capture probability. The test tells us how closely we came to meeting the constant capture probability assumption.

The $\chi^2$ test can be applied as follows:

$$\chi^2 = \sum_{i=1}^{k} \left[ \frac{[U_i - \hat{E}(U_i)]^2}{\hat{E}(U)_i} \right] \tag{7}$$

$$= \left[ \frac{[U_1 - \hat{E}(U)_1]^2}{\hat{E}(U_1)} + \frac{[U_2 - \hat{E}(U_2)]^2}{\hat{E}(U_2)} + \ldots + \frac{[U_k - \hat{E}(U_k)]^2}{\hat{E}(U_k)} \right]$$

where:

$\hat{E}(U_1)$ = the expected number of fish for the ith removal based on $\hat{P}$ (fig. 23) and the population estimate $= \hat{N}(1-\hat{P})^{i-1}(\hat{P})$

$\hat{P}$ = the estimated probability of capture during a single removal.

In our example:

$\hat{P} = 0.47$

$\hat{E}(U_1) = 978(1)(0.47) = 460$

$\hat{E}(U_2) = 978(0.53)(0.47) = 244$

$\hat{E}(U_3) = 978(0.53)^2(0.47) = 129$

$\hat{E}(U_4) = 978(0.53)^3(0.47) = 68.$

Therefore:

$$\chi^2 = \frac{(400-460)^2}{460} + \frac{(350-244)^2}{350} + \frac{(100-129)^2}{129} + \frac{(50-68)^2}{68}$$

$= 51.21$ with $k-2 = 2$ d.f.

The calculated $\chi^2$ is compared to respective $\chi^2$ table entry indicates that the removal pattern (400, 350, 100, and 50) did not give us a high goodness of fit, suggesting that a constant capture success was not achieved. On actual electrofishing, however, we have found that our field data allowed an adequate goodness of fit.

## Maximum Likelihood Model

Computer estimation of fish population sizes is accomplished with a maximum likelihood model that was developed with the assistance of Dr. Ken Burnham from the U.S. Fish and Wildlife Service's Western Energy Land Use team. This model uses the successive depletion of catch sizes to estimate the actual population size by determining the likelihood of possible population sizes greater than or equal to the total catch. The population size with the highest likelihood is considered the best estimate of the actual population size.

The first quantities to be determined are the total catch (T), which is a summation of the number of fish caught in each of k removals (U):

$$T = \sum_{i=1}^{k} U_i = U_1 + U_2 + \ldots + U_k \tag{8}$$

and a function of the removals called C:

$$C = \sum_{i=1}^{k} iU_i = U_1 + 2U_2 + \ldots + kU_k. \tag{9}$$

These two values are then used to calculate the likelihoods of the possible population sizes ($\hat{N}_b$):

$$\hat{N}_b = T + b \tag{10}$$

where b is any arbitrary integer.

To determine $\hat{N}_b$ (the population estimate), we need to calculate the value of $\hat{N}_b$ with the greatest likelihood of occurring. This is accomplished by searching for the value of $\hat{N}_b$ associated with the highest probability. To do this, we define the likelihood function of b, called $\emptyset(b)$, which is essentially the natural logarithm of the population estimate probability when $\hat{N}_b = T+b$. We look at actual probabilities, but they are extremely small (between 0 and 1). It is more convenient to work with natural log probabilities.

$$\text{Let } h(b) = \sum_{b=1}^{j} \ln\left(1 + \frac{T}{b}\right) \tag{11}$$

$$\text{Then } \emptyset(b) = h(b) + T \ln\left[\hat{P}(\hat{N}_b)\right] + (C - T + kb) \ln\left[1 - \hat{P}(\hat{N}_b)\right] \tag{12}$$

where the capture probability ($\hat{P}[\hat{N}_b]$) is:

$$\hat{P}(\hat{N}_b) = \frac{T}{C + kb} \tag{13}$$

and:

j = the value of b at which the natural log-likelihood equation $\emptyset(b)$ is maximized.

Considering the possibility that the population estimate equals the total catch, the special case of b=0 needs to be defined so that division by zero is avoided.

From this:

$$\emptyset(0) = T \ln\left[\hat{P}(\hat{N}_0)\right] + (C - T + kb) \ln\left[1 - \hat{P}(\hat{N}_0)\right] \tag{14}$$

where:

$$\hat{P}(\hat{N}_0) = \frac{T}{C}.$$

Then $\emptyset(b)$ is calculated sequentially over the range of b=0, 1, 2, . . . j. When the function $\emptyset(b)$ is maximized at $\emptyset(j)$, the population equals

$$\hat{N}_j = T + j \tag{15}$$

and the capture probability equals

$$\hat{P}(\hat{N}_j) = \hat{P}(T+j) = \frac{T}{C+k(\hat{N}-T)} = \frac{T}{C+kj} \qquad (16)$$

Calculation is too involved to illustrate here, but using the removal data from the previous example, the maximum likelihood population estimate is 973 compared to 978 from the Zippin approximation. Ninety-five percent confidence limits around $\hat{N}_j$ are easily determined by calculating the standard error of $\hat{N}$:

$$SE(\hat{N}_j) = \sqrt{\frac{\hat{N}[1-\hat{P}(\hat{N}_j)]^k \quad \{1-[1-\hat{P}(\hat{N}_j)]^k\}}{\{1-]1-\hat{P}(\hat{N}_j)]^k\}^2 \quad - \; [k\hat{P}(\hat{N})]^2 \quad [1-\hat{P}(\hat{N})_j)[^{k-1}}} \qquad (17)$$

$SE(\hat{N}_j) = 14.30.$

Therefore:

95 percent confidence limit lower $= \hat{N}_j - 1.96\ SE(\hat{N}_j)$

95 percent confidence limit upper $= \hat{N}_j + 1.96\ SE(\hat{N}_j)$

so 95 percent intervals equal:

$$\hat{N}_j \pm 1.96\ SE(\hat{N}). \qquad (18)$$

Using our previous example and a population estimate of 973, we calculate;

$\hat{N}_j = 973 \pm 28.02.$

The $\chi^2$ goodness of fit test for the Burnham maximum likelihood model is identical to that for the Zippin model except that it includes an extra term to account for the fish remaining in the stream after k removals.

$$\chi^2 = \sum_{i=1}^{k} \left[\frac{[U_i - \hat{E}(U_i)]^2}{E(U_i)}\right] + \left[\frac{[T - \hat{E}(T)]^2}{\hat{E}(T)}\right] \qquad (19)$$

where:

$U_i$ = the number of fish caught in removal i

$\hat{E}(U_i)$ = the expected catch from removal i

$= \hat{N}(1-\hat{P})^{i-1}(\hat{P})$

T = total catch

$\hat{E}(T)$ = expected total catch $= \sum_{i=1}^{k} E(U_i)$ .

From our example, we calculate $X^2 = 66.02$ with k-2 = 2 degrees of freedom.

Use of the Burnham method in 1979 and 1980 resulted in narrower confidence intervals. Also, improved electrofishing techniques may be partly responsible for the narrowed confidence intervals.

### Calculator Analysis

Hand calculators make the Seber-LeCren (1967) and Zippin (1958) methods simple to use. Also, calculators allow field checks of the collected data at the time of sampling to check electrofishing techniques and make sure that the required assumptions of capture are met. The successive catches can be graphed and if the plotted catches form along a linear regression line, constant capture and effort are usually indicated. If erratic catch data result, electrofishing methods must be reevaluated. If the erratic catch data are a function of nature, then nothing can be done.

**Table 11.** — Selected electrofishing population estimate results

| Stream | Species | Population estimates per 1,800-ft reach | Confidence interval (± percent of estimate) |
|---|---|---|---|
| Horton | Brook trout | 77 | 3 |
| Gance | Cutthroat trout | 1,135 | 2 |
| Frenchman | Brook trout | 716 | 5 |
| Frenchman | Chinook salmon | 60 | [1]28 |
| Frenchman | Sculpin | 710 | 6 |
| Johnson | Brook trout | 346 | 5 |
| South Fork Salmon River | Bull trout | 682 | 4 |
| Tabor | Rainbow trout | 114 | 4 |
| Bear Valley | Sculpin | 6,577 | 2 |
| Bear Valley | Chinook salmon | 44 | 11 |
| Bear Valley | Whitefish | 121 | [1]40 |

[1]Resulted from poor removal pattern.

**Individual Fish Species**

Estimates may have to be computed separately for individual fish species if they vary in their probability of capture. Species not having the same probability of capture can be evaluated separately and their probabilities added together to estimate total standing crop. We have found that rainbow trout (*Salmo gairdneri* Richardson), cutthroat trout (*Salmo clarki* Richardson), brook trout (*Salvelinus fontinalis* [Mitchill], bull trout (*Salvelinus confluentus* Suckley), and chinook salmon can be grouped together to determine total fish standing crops because their probability of capture is about the same. However, sculpin (*Cottus* sp.) and whitefish (*Prosopium* sp.) must be treated separately as their probabilities of capture are different.

Table 11 gives selected population estimates (at the 95 percent confidence level) using the Burnham maximum likelihood four-step removal method of determining fish population estimates.

## Toxicants

### Sodium Cyanide

Sodium cyanide (NaCn) used under strict safety precautions by trained fishery specialists is a cheap, fast, efficient, toxicant to use in collecting fish for determining fish standing crop, species composition, health, and survival rates. This compound can be purchased from chemical companies for about $1.00 per kilogram. The material is environmentally nonpersistent, but it is toxic to fish at all temperatures, and toxicity increases with temperature and is related to metabolic rates. The small amounts of compound needed to sample fish in small reaches of streams make it effective in hard-to-reach streams that are heavily vegetated, or in backcountry areas without access roads, where transporting electrofishers would be difficult. There is a need for a fish toxicant, such as sodium cyanide, that will facilitate fish removal and yet permit their return to the stream alive. The effects on fish from applied application rates of sodium cyanide over sufficient time for effects to take place are shown below:

| Rate[5] | Effect |
|---|---|
| 1.0 to 1.5 | Trout can be collected and released unharmed, but whitefish die. |
| 3.0 | Trout will die; some more tolerant nongame fish can be collected. |
| 5.0 | All fish species can be collected, but high mortality occurs in most species. |
| 6.0 | All species die except possibly some carp and suckers. |

Stream reaches selected for sampling need to be blocked off from fish escape using the same procedures discussed under electrofishing. It is suggested that these reaches be less than 300 ft (100 m) in length and less than 100 ft$^3$/s (2.8 m$^3$/s) in flow for a sufficient fish sample size with most of the population being affected by the toxicant.

Once the flow is determined the proper amount of (NaCN) is applied to the water column by placing the required number of Cyanobriks (each brick weighs about 1 ounce [20.3 g]) in a riffle at the upper end of the sample reach (Wiley and others 1975). This is an application rate and not a concentration rate. Dye is added so the flow of cyanide through the reach can be followed. Cyanobriks are manufactured by DuPont DeNemours and Company, Inc., and sold by the McKennon Chemical Company. Cyanegg, a pellet form, also can be used. The number of bricks required depends on the objectives of the sampling program and the species or group of species involved. The rate of application in the tabulation is based on water temperatures of 55° F (12.8° C) and pH of 7. Generally, 1 to 1.5 ounces (28.3 to 42.5 g) of NaCN per ft$^3$/s of flow and 3.0 to 3.5 ounces (84.9 to 99.1 g) of NaCN per ft$^3$/s of flow is effective in sampling fish in cold and warm water streams, respectively. Because of decreased metabolic rate (depressed effect of cyanide) on fish in cool water, it is recommended that NaCN not be used at water temperatures less than 50° F (10° C) (Wiley, personal communication).

If the user is working on habitats with mixed species and all fish must be returned to the stream unharmed, it means making more than one addition of the toxicant. For example, one might have to use 1.5 p/m of NaCN to collect the brown trout (*Salmo trutta Linnaeus*) and remove them from the sample area to an upstream site, and then make another run at 6.0 p/m to collect suckers (*Catastomus* sp.) and carp (*Cyprinus* sp.). Also, pools may wind up with heavier concentration of NaCN than riffles and must be watched carefully to make sure that fish can be quickly removed to eliminate mortality. Bridges (1958) found 1 p/m of NaCN in ponds produced complete kills on all species tested. However, if the fish were immediately collected upon showing stress and placed in fresh water, they survived. The size of the fish had no effect on the success of the toxicant. Recent work by Wiley in Wyoming on cutthroat trout showed the exposures for 10, 15, and 20 minutes to 1 p/m NaCN did not affect their growth or survival during the following 6-month period (Wiley, personal communication).

Sodium cyanide is dangerous to humans, so users are required to wear waders, raincoats, and rubber gloves when making contact with it (Wiley and others 1975). When transferring the chemical directly, a gas mask approved for cyanide gas or dust removal must be used. The compound should be used only in well ventilated areas. Avoid stagnant air pockets such as those that occur along streams in the early morning. Wiley and others (1975) list such safety rules as (1) cyanide must be stored in water tight containers under uniform temperatures and (2) fresh supplies of amyl nitrite inhalents must be on hand if needed to combat cyanide toxicity. At least two persons should be trained in cardiopulmonary resuscitation.

Sodium cyanide is not a registered fish toxicant. However, the Environmental Protection Agency has indicated that, when used in fishery research, it is not subject to the provisions of the Federal Insecticide, Fungicide, and Rodenticide Act. This statement should be checked prior to use as rules and regulations continually change. Sodium cyanide is an effective tool, but must be used with caution — never around domestic water supplies and always in well ventilated areas and under close supervision.

### Rotenone

Over the years, rotenone has been the most widely used toxicant for fish collection or elimination. This chemical is used under much the same conditions as cyanide, but is usually in liquid form. A drip station is set up in a riffle to dispense the liquid at the concentration required. A drawback of rotenone over cyanide is that the carriers and solvents used to form the liquid repel fish more than cyanide does; therefore, blocking nets are required. Also, rotenone-toxified fish do not survive.

Toxicity of rotenone is greatest at water temperatures between 50° and 70° F (10° and 21° C) and drops as temperature

[5]This is an application rate per liter of streamflow and is not a concentration rate per liter.

decreases. In shallow streams, the toxicity decreases about 30 percent a day. This residual toxicity is another drawback because the chemical can travel long distances in flowing waters.

Potassium permanganate can be used to neutralize the rotenone effects. In standing waters, the potassium permanganate necessary to oxidize rotenone is equal to the amount of rotenone applied plus the chlorine demand of the water. In streams, this amount has been estimated as 2.5 mg/liter per cubic foot per second during the entire time the rotenone is passing through the neutralization point.

Species susceptibility ranges from 0.2 mg/liter for trout to 2.0 mg/liter for carp. At the recommended stream temperature of between 55° and 75° F (12.8° to 23.9° C) the application of 2 ounces (0.03 $m^3$) of 5 percent emulsified rotenone per cubic foot per second will obtain desired fish kills. For possible fish survival after collection, the fish must be netted immediately and placed in clean water. As with fish affected by cyanide, many fish never surface, but sink to the bottom. Although rotenone has been the most popular fish toxicant, we recommend that its use be avoided. The fish collection methods discussed previously do a better all-round job. The unpredictable nature of rotenone when applied to streams and the potential of "killing out" large stream areas has led many investigators to shun the use of this chemical for sampling purposes.

## Explosives

### Primacord

Explosion of primacord in small streams (up to stream order 4 or possibly 5) can assure an almost 100 percent collection of the fish population within the sample area. Primacard detonates at over 21,000 ft/s (6401 m/s), or essentially instantaneously. This explosive has a potential for a total kill of fish within 10 to 15 ft of the cord, provided that no major obstructions occur between the explosive and the fish (table 12).

**Table 12.** — Number of strands of standard size primacord to use in various stream widths and depths to assure complete fish mortality (Platts 1974)

| Channel depth | Channel width 8 | 8-15 | 15-20 | 20-25 | 25-30 |
|---|---|---|---|---|---|
| | *Feet* | | | | |
| < 6 | 1 | 2 | 2 | 2 | 3 |
| < 6-10 | 1 | 1 | 2 | 2 | 2 |
| 10.1-15 | 2 | 2 | 3 | 3 | 3 |

Primacord is not affected by air temperatures and can be stored for extended periods without deterioration. Water does not affect the cord for the short period of time it takes to set up the explosive grid and the cord will explode continuously even when the core is wet. Reinforced primacord is recommended because it has good flexibility, ties easily, holds well knotted, and has excellent resistance to water.

The stream area to be sampled should be blocked off with a net with mesh size small enough to keep young-of-the-year fish from leaving the area (0.125 inch and no larger than 0.225 inch [3.48 mm to 5.7 mm]). The nets must be placed at least 6 ft (2 m) above and below the sample area to keep the explosion from damaging the nets. Nets are needed for two reasons: (1) to keep fish from moving out of the area while the grid is being laid and (2) to stop dead fish from floating downstream out of the sample area after the explosion. If fish will not move out of the sample area during installation of the cord and all floating fish can be collected after the explosion, then nets are not needed.

The primacord is laid along the stream bottom, but the grid coverage must abide by the guidelines in table 12. If a major obstacle in the channel would shunt the force of the blast in the wrong direction, the cord is wrapped around the obstacle or placed on both sides of it. After the cord is laid out, it is detonated by using an electric blasting cap (from an approved electrical source) attached to one end of the trunkline. Primacord is relatively insensitive to heat, impact, friction electricity, or static electricity, so premature or accidental explosion is unlikely. Although relatively safe, it should be used only by qualified persons. No aquatic scientist should use this method until he or she has read "Primacord Detonating Fuse — What It Is And How To Use It" by the Ensign-Bickford Company, Simsbury, Conn., published in 1963. Also, each user should take a training course in explosives and be certified to handle primacord and blasting caps.

We found that electric blasting caps were the easiest and safest way of exploding the cord because the wires conducting the electrical current have safety shunts. Consequently, the cord will not detonate until this safety device is removed. The cap is simply attached to the primacord by electrician's tape, making sure that the "business end" of the cap is always pointed in the same direction as the primacord. The long electrical wires leading to the cap allow the users to get behind a protective block or far enough away from the blast for complete protection. Another reason for using electric blasting caps is that the users can detonate the cord at any desired instant. There is always the slim chance that the cap can be set off by static electricity that would not be stopped by the shunt, so the user should wear clothing of either wool or cotton, but not a mix of the two. Users should never remove or put on clothing while working with explosives. **(Blasting caps must not be brought close to the primacord until the cap is actually taped to the cord.)**

After each explosion, the dead fish are recovered by searching the stream channel; most will be on the bottom. The streambanks must also be inspected because occasionally a fish will be blown out of the channel. Usually, if they are blown above the water surface, they fall into the channel. The net should not be pulled until the water clears or until the water in the sampled area at time of explosion has passed through the downstream net. The net must be inspected closely as many of the fish will drift into it.

Abiding by the conditions for primacord use outlined in table 12, we sampled 2.75 miles (4.6 km) of stream in 39 tributaries in the South Fork Salmon River, Idaho. With constant checking, we determined that (to stream order 4) the fish sample collected was close to 100 percent of the true population. The streams were small enough for the blockage nets to be effective and the clear water allowed good observation of dead fish.

## Direct Underwater Observation

### Redd Counting[6]

The term "redd" is applied to salmonid nests containing embryos, but redd size varies according to the species and to female size. Salmon redd sizes vary from 18 to 137 $ft^2$ (1.7 to 12.7 $m^2$). Newly formed redds appear lighter in color than the undisturbed channel, except in gravel of basaltic origin, where the difference is much less apparent, making the redds more difficult to detect.

Training of redd-counting personnel should begin under the supervision of an experienced observer until counts are comparable. Redds should be closely examined by the trainee with parti-

[6]Contributed by Tom Welsh, Fishery Consultant, McCall, Idaho.

cular attention to the appearance of overlapping redds. If aerial (from an airplane or helicopter) counts are to be made, the trainee should have an intimate familiarity with the spawning areas. After the aerial count, he should reexamine the spawning riffles and compare the ground and aerial counts. "False redds," initial egg pockets that have been abandoned by the female before egg deposition, should not be counted.

Redd counting in streams is most easily accomplished in late summer when some salmonid species spawn and streams are low and clear. The counting of redds of spawning steelhead trout has had little success because of the higher, turbid flows in the spring. The smaller species of salmon habitually spawn in concentrated numbers, making detection of individual redds extremely difficult. In this case aerial fish counts are probably less subject to error. Aerial counts of adult salmon spawners can be used to detect differences in population size of ± 50 percent (Bevan 1961).

Newly constructed redds become progressively less discernible over time because periphyton is reestablished over the disturbed areas and, together with silt deposition, soon causes the lighter coloration of the redd to disappear. Watson (1970) found that Columbia River fall chinook salmon redds were detectable up to 6 weeks after their construction. The most accurate redd counts are made while the female is still protecting the redd. Earlier counts miss females that have not moved onto the riffles, whereas later counts miss some redds constructed earlier that have lost contrast with the surrounding substrate.

Redd counts should be used only as an index to determine large annual changes in population size. They are of limited value in determining population size for any given year, but can provide valuable time-series trends that assist in determining whether populations are stable, decreasing, or increasing. Redd counts can be biased by numerous variables, including streamflow, observer qualifications, water turbidity, light intensity, light reflection, and the changing of observers from year to year.

**Ground counts** — Ground counts are made while walking or using a boat and are usually more accurate and less costly than aerial counts because the observer has more time to examine each redd. Ground counts are best used on small, meandering streams with large amounts of overhanging vegetation or in steep-walled canyons where flying would be hazardous. If the spawning area is too extensive for complete counting, trend count areas can be established, preferably near the center of the spawning area, to develop yearly trend information.

**Underwater redd counts.** — Observations of deepwater redds are possible only with the use of scuba gear. Sockeye salmon (Oncorhynchus nerka [Walbaum]) have been detected spawning as deep as 80 ft (24.4 m) in lakes, and fall chinook as deep as 40 ft (12.2 m) in the Columbia River. Actual counts of redds are difficult with scuba gear; so the gear should be used only for determining the presence or absence of spawning redds. If divers can delineate the outer boundaries of the spawning area, then establish the average redd size, the number of redds can be crudely calculated. Underwater redd counts are slow and laborious, and counters must face the inherent danger of deep diving in rapidly flowing water.

**Aerial redd counting.** — Aerial trend counts have proven to be a fast, efficient method of providing an index of the spawning population. No valid comparison can be made between different observers' counts unless they have counted together and standardized their redd counting procedures.

In large rivers or in spawning areas with difficult access, aerial counts may be the only feasible method of providing population indexes. In areas of heavy redd concentrations, slower airspeeds (use of helicopters) permit the counting of individual redds, rather than multiples of 10 as required at faster airspeeds. Also, the observer can make nearly vertical observations, which increases the depth that redds can be detected, a considerable advantage on large, deep rivers. If an observer begins to suffer from motion sickness, the count should be terminated.

Aerial photographs provide a permanent record of spawning areas and can be used to estimate redd numbers. In areas of heavy redd concentration, the viewer can mark the individual redds and avoid either missing redds or duplicating counts.

Using color infrared, color positive, and color negative film in a camera equipped with a 153-mm lens in a fixed-wing airplane and photographing from a height of 1,200 ft (365.8 m) has proved successful for documenting redds for counting. The major disadvantage is cost, which averages about $3,000/mile ($1,865/km) on the Hanford reach of the Columbia river.

### Snorkel and Scuba[7]

Under some circumstances, fish observations made while using snorkel and scuba gear may produce species composition and abundance data that are superior to those obtained by more conventional methods (Goldstein 1978; Griffith and Schill in press). The reasons are that: these methods may be used successfully in streams with low conductivity and substantial depth where the effectiveness of other methods, such as electrofishing, is reduced; data can be obtained with less time and money; heavy equipment may not be required, which makes the technique valuable in remote roadless areas; and fish are not handled and so are not injured. In addition, fish are observed in the habitat they have selected and not where they have been chased prior to capture. Therefore, better insight into their distribution and behavior can be gained.

Underwater observation procedures entail some limitations however, such as: water must be clear enough to allow identification of fish a minimum of about 5 ft (1.5 m) away; the observer must always keep the stream bottom in view for best results; the method does not work in areas that are too shallow or too swift; and the direct measurement of length and weight is not possible. Also, fish may escape past the diver and there is always the possibility of counting the same fish more than once. If necessary, however, individual fish may be killed with a "gun" that detonates electrical blasting caps (Everest 1978).

Two potential sources of bias must be accounted for to obtain reliable data when using snorkel or scuba methods. One potential source of bias lies in the fact that the reaction of fish to underwater observers varies greatly among fish species. Some species, such as the mountain whitefish, *Prosopium williamsoni* (Girard), that school or aggregate in large numbers may be difficult or impossible to census accurately. Other species, such as some darters (*Etheostoma* sp.) and sculpins, may be too secretive or evasive to be censused during the day, although night surveys may be effective. Trout and salmon often hold their territories in the presence of the observer and are relatively ideal to census. The second potential source of bias is the variability in performance among individual observers. Each observer, therefore, should compare his or her performance with that of others or individually check themselves on a stream section that holds a known number of fish. When fish censusing is repeated periodically in a stream, the same observer(s) should be used on each occasion.

Safety considerations cannot be overemphasized. All stream sections to be censused must be studied from the bank to determine

[7]Contributed by Dr. J. S. Griffith, Associate Professor, Idaho State University, Pocatello.

if there are any hazardous areas. Snorkel or scuba work should never be done alone, and ropes should never be attached to an observer's body while that person is in the water. A scuba course should be completed before using this technique. Snorkeling presents little risk if the correct equipment and safety procedures are used.

**Procedures.** — A neoprene suit of the wet or dry type, preferably ¼-inch (6.4-mm) thick, with boots, gloves, and hood is generally needed for warmth. The wet suit allows exposure to 60° F (16° C) for several hours, depending upon the individual. The dry suit, which is similar to a wet suit but has seals on ankles, wrists, and neck to exclude water, can be used in colder water or for longer exposure. The suit should be custom-fitted for each individual to maximize its effectiveness. Fins are needed in large rivers to increase maneuverability, but are a hindrance in smaller streams. At present, a complete wet suit costs about $250 from the manufacturer and a dry suit costs about $80 more.

Observers must move in the water with a minimum of disturbance and should look as far ahead as possible to locate the fish on the fringe of vision. Several practice sessions are needed to become effective in locating fish.

The underwater visibility should be measured before each day's observations. Use an object the same size as the fish to be observed (a flashlight, for example) and measure the maximum distance at which it can be seen. Record this measurement for comparison with subsequent observations in that reach.

Each census must be planned for a successful counting. Observers must determine the fish species to be censused and record the size groups or age groups of each species recorded, the time the census is to be taken, the habitat to be included in the sample, and the direction of observation routes in the stream.

If the fish community is diverse, it may not be possible for one observer to record the numbers of every species. In that case, the observer should select only key species to count, or several observers should be used and each should count different species. Fish counts can be recorded on hand-held tally counters or on underwater slates.

Young-of-the-year can usually be distinguished from older fish. If there is minimal overlap in size between successive age groups and the observer has prior knowledge of the relationship between age and size of fish in the population, it is feasible to keep separate counts for each age group (Griffith 1981). Direct estimation of fish length also may be feasible under some circumstances. Griffith and Fuller (1979) marked 45 trout 8.5 to 17.5 inches (216 to 445 mm) in length with color-coded tags and then had five observers estimate their length by sight only. Without advance preparation, 52 to 72 percent of the estimates by each observer fell within 1 inch (25 mm) of the actual fish length. After 1 hour of practice on objects of known length, the most experienced observer estimated lengths within 1 inch (25 mm) 90 percent of the time, with a mean of 62 percent for all observers. Each individual must train himself to compensate for the 1.33 underwater magnification factor by practicing and perhaps carrying a short ruler taped to the wrist or making length units on a glove.

The behavior of the fish should be considered when selecting the time of censusing. Daytime sampling is adequate or preferable for many fish species and is more convenient for the observer. Consistency is important. Cloudy days when visibility is reduced should be avoided, and shadows on sunny days should be minimized by diving around midday. If censusing is to be done at night, it should be done consistently on the same phase of the moon, as behavior and distribution of some fish species may vary between phases.

The only habitat that can be effectively snorkeled in small streams (usually second and third order) may be the pools. In larger streams, basic habitat types can be stratified and counts made separately for each, or all habitats can be grouped together, depending on the needs of the observer. If the habitat is uniform, the starting point for each census should be selected in a random manner. If an area is to be recensused in the future, it is critical that its boundaries be permanently marked with metal stakes and the reach photographed.

There are three possible directions to be used by the observer in conducting the census. Moving upstream is the most effective, if it is feasible. This can be done in small streams of low velocity where walking or crawling is possible. On larger streams, the observer must travel with the current. In some areas, the water may be shallow enough or slow enough to permit the running of transects from bank to bank perpendicular to the flow, but this is uncommon.

Most underwater counts are done to establish trends in species composition or species density to compare between areas, seasons, or years. Therefore such trend counts are designed as indexes of the relative status of a population rather than rigorous population estimates. With proper planning and careful execution, however, population estimates can be made under some circumstances.

**Population estimation with single observer.** — This technique should be used when the observer can scan the stream from bank to bank. Several passes should be made through the initial section to determine if such repeat counts are consistent. If not, the procedure must either be adjusted to gain the necessary accuracy or the technique should be abandoned. Another accuracy check is to have a second observer make the same count at the same time or immediately following the first observer's pass, if two observers would increase disturbance to fish.

The habitat types within the stream reach are counted separately or are combined, depending upon the design selected. If there is an indication that fish within the areas counted are not distributed randomly, the data should be tested for spatial distribution (Elliott 1977) by examining the relationship between the variance and mean of the population. If variance is significantly less than the mean, a uniform or underdispersed distribution is present; and if variance significantly exceeds the mean, the fish are clumped or overdispersed. If these conditions exist, data should be transformed as necessary. Confidence intervals around the mean are then calculated as described previously and expressed in terms of numbers of fish per unit of stream length or surface area.

**Population estimation with several observers.** — This approach is more complicated from the standpoint of logistics, but is necessary to obtain better data on large rivers. Observers in underwater gear drift with the current counting routes in lanes. Lane width is dictated by underwater visibility. To be effective, observers must stay in a line perpendicular to the current. Thin fiberglass or plastic poles about 16 ft (4.9 m) long are held by observers to maintain position in the current and to maintain correct width of counting lanes (Griffith and Schill in press). Each observer counts fish passed on one side of the observer's body only. Since shallow stream margins are likely to contain more juvenile fish (and perhaps some different species), fish should be counted separately. Confidence intervals can then be calculated as described above.

**Population estimation using mark-recapture.** — If it is possible to mark (by angling or another technique) a number of fish with color-coded tags that can be recognized by underwater observers (fin-clips are not adequate), population estimates can be made. Observers record the numbers of tagged and untagged fish of the appropriate species that are seen. Using these data, the population can be estimated using the Petersen formula $N = MC/R$, where N is the estimated population size, M is the number of tagged fish released, C is the number of fish observed by the observers, and R is the number of tagged fish observed.

## MACROINVERTEBRATE ANALYSIS

By convention, freshwater macroinvertebrates are those animals without backbones that are large enough to be seen without magnification. The main taxonomic groups of macroinvertebrates occupying freshwater environments are annelids, crustaceans, flatworms, mollusks, and insects (usually predominant). Their lower size limit has been variously defined by their retention on screens or nets with mesh openings of 0.023 inches (0.589 mm) (American Public Health Association 1976; Weber 1973), 0.011 inches (0.280 mm) (Winget and Mangum 1979), and 0.008 inches (0.210 mm) (Greeson and others 1977). The latter appears to be most suitable for obtaining representative collections of most macroinvertebrates in flowing waters (the principal exception is midge larvae) and has been adopted by the U.S. Geological Survey (Greeson and others 1977). A 0.210-mm mesh opening is equivalent to a U.S. Standard No. 70 sieve.

Macroinvertebrates are important intermediaries in the utilization of plant material, such as algae, vascular hydrophytes, leaves, and wood, and the recycling of nutrients in aquatic environments. They are a major food source for fish and serve to determine the well-being of those populations. In particular, the macroinvertebrates possess several characteristics that make them useful for detecting environmental perturbations: (1) most members of this community possess limited mobility so that their status reflects conditions in the immediate vicinity of the collection site, (2) most of the organisms (mussels are the main exception) have life spans of several months to a few years. Thus, their characteristics are a function of conditions during the relatively recent past, including sporadic influences that would be difficult to detect by periodic microbial or chemical analysis.

Some of the first things that a resource manager must consider in the utilization of macroinvertebrates as an investigative tool are whether the sampling should be qualitative or quantitative and whether to concentrate on selected "indicator species" or to include the entire community. Because of constraints of time and money, the temptation often is to employ qualitative collections and/or to examine selected groups. But this choice often proves most costly in the long run. It provides less information, thereby greatly reducing the reliability and usefulness of the data; yet the same or more specialized expertise may be required. Consequently, some form of quantitative or semiquantitative sampling of the full macroinvertebrate community is recommended for the situations most likely to be encountered by users of this manual.

The purpose of semiquantitative sampling is to determine the relative abundance of each species in a standardized manner so that spatial and temporal changes in numbers and/or biomass can be measured. Sampling methods include the use of uniform substrates (natural or arrificial) or collection with a dip net in a standardized manner or over an established time period. Values are reported per unit sample rather than per area. Expression of the results as a percentage of the total numbers collected at a site is to be avoided since the values obtained for each taxon are strongly influenced by the values of the other groups collected (Elliott 1977).

The purpose of quantitative sampling is to determine the absolute abundance of each species per unit area of habitat. The samples provide measures of population densities which may be used to detect variations in time and space and which are essential for the determination of biological production. In addition, quantitative samples may be more representative of actual conditions than semiquantitative ones. For example, introduced substrata may provide conditions considerably different from those actually found in the environment.

### Sampling Strategy

Design of a proper sampling scheme must take into account the location of sample collections, when and how often the collections are to be made (sampling frequency), and the number of replicates to be obtained (sample size). In addition, sampling variability resulting from sampling device operations, physical features of the environment, laboratory sorting procedures, and biological features of the study populations may confound interpretations of the results. There are a number of sources of information for guidance in addressing these questions, including reviews by Elliott (1977), Greeson and others (1977), Hellawell (1978), Hynes (1970), Resh (1979), Southwood (1978), and Weber (1973).

#### Sample Location

Sampling location involves both selection of the collecting sites (stations) and determination of the specific location from which the samples are to be taken. Sample site selection is determined by the specific question being addressed. For example, a point-source of pollution or a localized problem area would require a minium of one site each above and below the affected area. Additional downstream stations would be necessary to assess the extent of influence of the disturbance and extra upstream stations would be useful to establish the variation between control sites (Hellawell 1978). Tracking the effect of a nonpoint souce disturbance might involve locating a number of stations along a length of stream or establishing collecting sites at control and disturbed locations in different watersheds (for example, grazed versus ungrazed, burned versus unburned).

When more than one site is being examined, one may choose to sample one or a few standard habitat types (especially appropriate in semiquantitative studies) or to obtain samples representative of the overall conditions at each site (as is usually required in quantitative programs). Riffles are commonly chosen as standard sample sites because of their relative uniformity in terms of substratum and current, their higher biotic diversity, and their greater accessibility except during flood. However, such erosional areas clearly are unsuitable or at least inadequate if one is interested in studying the effects of an agent, such as inorganic sediment, that would be apparent mainly in depositional areas. Likewise, if one is interested in comparing the productivity of one section of stream with another, then sampling all major habitats and expressing results as an area-weighted mean may be the most satisfactory approach. With this approach, when the area is divided into several strata (subhabitats), the sampling design is termed "stratified."

Regardless of which of the above strategies is used, a proper sampling scheme requires that replicate samples within a site be taken with conscious avoidance of bias. This may be done through either random or systematic sampling. Random sampling is done most easily by dividing the area into quadrants, each the size of a replicate sample, and then selecting the quadrants to be sampled by use of a random numbers table. The distribution of macroinvertebrates generally is heterogeneous (clumped), largely as a result of the nonrandom distribution of microenvironmental features, especially the substratum and the current. Consequently, sampling that is strictly random will have a relatively large error when applied to a natural population. For this reason stratified random sampling is often preferred.

In systematic sampling, the first unit in the sample is selected at random and the next units are established at fixed intervals from the first. Additional details and examples are given by Elliott (1977: 131-136), Greeson and others (1977: part 1, 10-19), and Weber (1973: 4-6). Users of this manual probably will find the systematic approach appropriate in most cases and easiest to apply. A common procedure for intermediate-sized, third- to fifth-order streams might be to mark off a length of stream or a riffle at established intervals, such as 3.3 ft (1 m), with each interval being the site of a potential sampling transect. The specific transects to be sampled could be selected at random from a container holding the numbers of all of the transects present. Upon reaching the selected transect, samples could be collected from the center of the stream, and from half of the way and one-fourth of the way between the center and each bank for a total of five replicates. In smaller, first- and second-order streams, the samples might be taken at fixed distances down the stream rather than across it.

### Sample Frequency

The distribution and abundance of many macroinvertebrates and, consequently, their community composition are subject to wide seasonal variations. Thus, when conducting comparative studies, the investigator must avoid the confounding effects of these seasonal changes; collections made in different locations must be from the same time period (week or month) to minimize variations resulting from life cycle changes. If only one collection a year is possible, it should be taken in the spring when a majority of the insects present are well developed and easier to identify. The collections also should be made before spring runoff because high flows disturb the stream bottom and make working the stream difficult. If only two collections a year are made, the second set should be taken in late summer. All the same, monthly collections are desirable. However, in situations where the full community makeup and life cycle variations are not known, a minimum of one collection per season is recommended. Additional collections may be needed to pinpoint the effects of specific events and should be made just before and after an event, such as road construction.

### Sample Size

The size of the mean, the degree of aggregation, and the desired precision of the mean estimate will influence the number of samples required to estimate densities of benthic populations (Resh 1979). A relatively large number of sample replicates, possibly several hundred, must be collected from each site if the goal of the sampling program is to describe the macroinvertebrates of an area with a high degree of accuracy. The number could increase many times if a stratified sampling scheme is called for. However, where most surveys are concerned, a high degree of accuracy may be counterproductive because extremely subtle, but statistically significant differences may be tolerated by the investigator or resource manager and reasonably rapid turnaround of results may be required; therefore, a compromise must be made between statistical accuracy and time and labor.

Three samples per habitat type is the absolute minimum required in any study and might be sufficient for a general faunal survey of a stream (Cairns and Dickson 1971). Five replicates per habitat would increase the statistical power of the samples with relatively little additional effort. For example, increasing the sample size (N) from 3 to 5 will (at $P<0.05$ and $N-1$ degrees of freedom) decrease the Student's t distribution (appendix 1) by $1.55 \times t = 4.303$ versus $t = 2.776$, whereas increasing the sample size from 5 to 60 will decrease t by less than half that much to $t = 2.00$ (appendix 1). Therefore, it is recommended that a minimum of five samples per habitat type be taken in the situations likely to be encountered by the users of this manual. In general, a larger number of replicates will be required to adequately represent the mean for a macroinvertebrate community consisting of a large number of species with a patchy distribution of individuals (the usual case in most unpolluted riffles) than will be required for a community represented by large numbers of a few species evenly distributed in the stream.

Elliott (1977: 129-131) describes two techniques for determining a suitable sample size. The first involves taking groups of five replicates at random, calculating the means for each 5, 10, 15, etc., units, and then plotting these against sample size. When the mean value ceases to fluctuate, a suitable sample size has been reached and this sample size can be used for that particular station or subhabitat. Since it is often impossible to calculate means at the time of sampling, this method is of limited application. In the second method, the ratio of standard error to arithmetic mean ($\bar{x}$) is taken as an index of precision (D). Therefore, sample size (N) can be calculated for a specified degree of precision by using the equation:

$$N = \left(\frac{ts}{Dx}\right)^2,$$

where D = relative error in terms of percentage confidence limits of the mean, s = standard deviation, and t = Student's t for the required probability. If, for example, in a preliminary survey or a previous set of samples, a mean number of individuals per sample was found to be 385 and the standard deviation 244, then for a relative error of ±40 percent (equal to a standard error of about 20 percent, a reasonable level in most macroinvertebrate samples) with a probability of 95 percent ($t \cong 2$). Entering those numbers into the formula

$$N = \left(\frac{ts}{D\bar{x}}\right)^2,$$

we get

$$\left(\frac{2 \times 244}{0.4 \times 385}\right)^2,$$

which equals about 10 samples.

## Sampling Methods

A number of possible sampling devices have been described for use in streams (American Public Health Association 1976; Greeson and others 1977; Hellawell 1978; Hynes 1970; Welch 1948). However, each device has its own sources of error and, since these are seldom known and are rarely identical between different types of samplers, it is well to limit the selection to a few relatively standard forms thereby facilitating comparison of results obtained by different workers. In the United States, of the semiquantitative samplers (fig. 24A, B, C, and D), the most common for use in streams are the multiplate (Hester and Dendy 1962) and basket (Mason and others 1967, 1973) samplers (fig. 24C, D, and E), whereas the most widely used quantitative devices are the Surber (Surber 1937) and modified Hess samplers (Waters and Knapp 1961) (fig. 24A and B). In streams that are too deep to wade, the semiquantitative collapsible basket developed by Bull

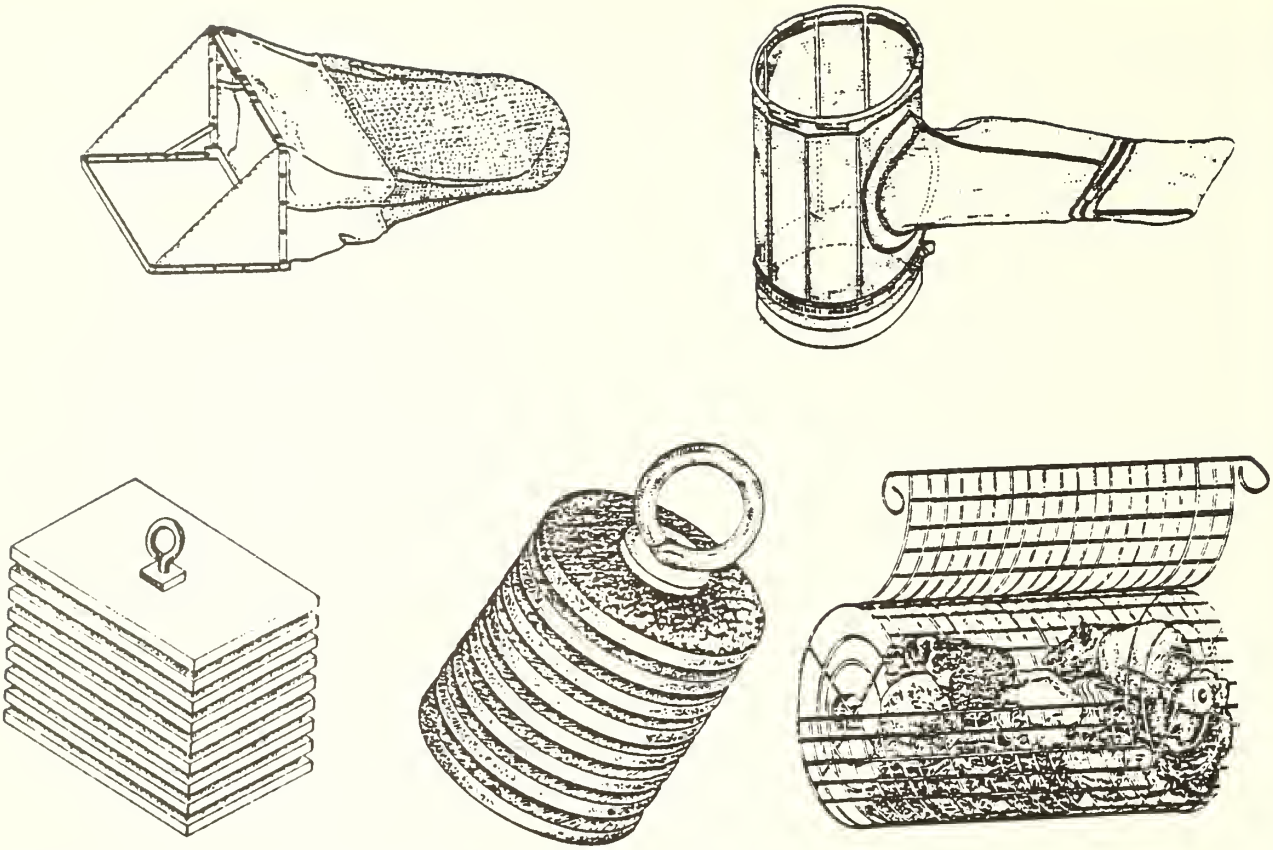


Figure 24. — Sampling devices for stream macroinvertebrates: (A) Surber sampler; (B) modified Hess net; (C) square; (D) circular versions of multiplate sampler; and (E) basket sampler. Illustrations A, B, and E are from Merritt and Cummins (1978) and are used with the authors' permission.

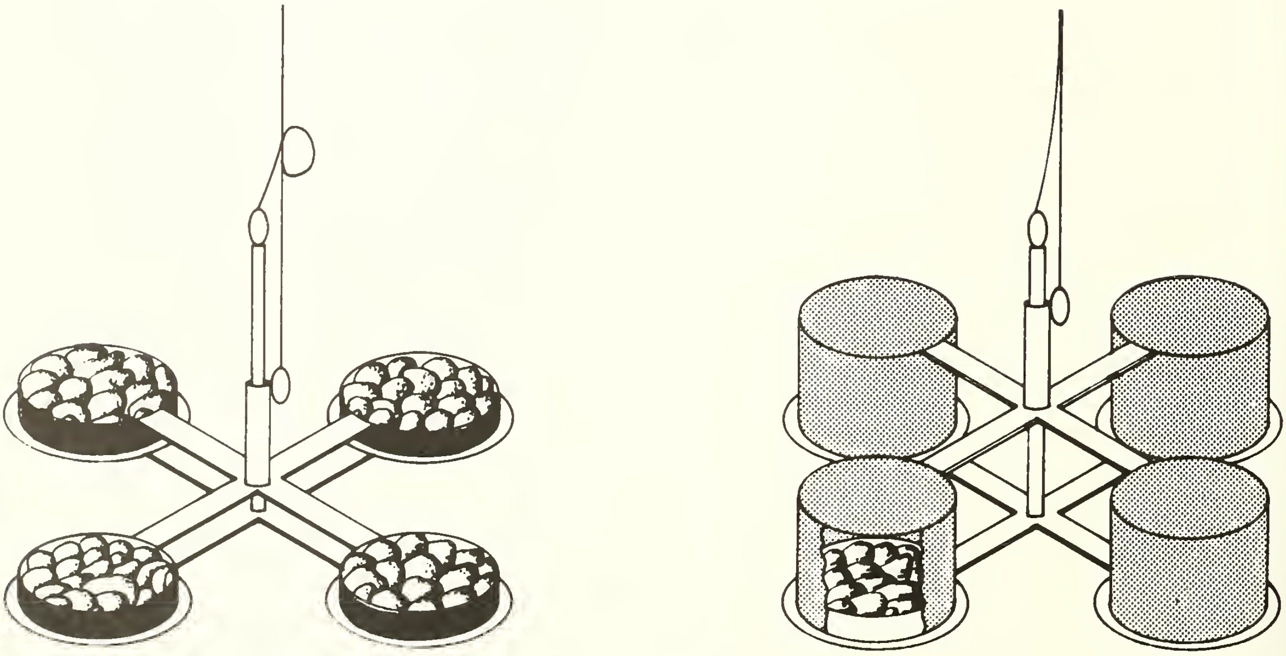


Figure 25. — Collapsible basket with substrate sampler (left) resting on streambed (right) being retrieved. (After B. Malmquist and L.M. Nilson, personal communication.)

(1968) and modified by Malmquist and Nilsson (personal communication) and the quantitative suction device described by Gale and Thompson (1975) are widely applicable (fig. 25 and 26). Procedures for the use of the various sampling devices are described in detail by Greeson and others (1977), Lind (1979), Weber (1973), and Welch (1948). Major items of consideration are described below

The specific sampling location should be approached from downstream and the collecting net placed into position as quickly as possible to reduce the potential for escape by the macroinvertebrates. For semiquantitative samplers, a hand-held dip net or specially fabricated net with a mesh of 0.008 inch (0.210 mm) is used to enclose the sampler, which is then carried to shore. The sampler and net contents may be placed directly into a container of preservative or the sampler may be disassembled at streamside, the plates or rocks placed in a tray of water and scrubbed clean with a brush, and the contents of the tray passed through the net before being placed in the container of preservative. If circular multiplate samplers having 3-inch (75 mm) diameter plates and 1-inch (25 mm) diameter spacers are used, the sampler can be placed directly into a widemouth quart jar. For quantitative samplers, the bottom frame of the Surber or Hess net should be pressed tightly against the stream bottom to avoid contamination from outside the sample area. On irregular bottoms, a more complete seal can be obtained by lining the bottom of the sampler with foam rubber, burlap, or other compressible material. The larger rocks should be lifted, scrubbed at the mouth of the net opening, and removed from the sampler. Thoroughly disturb the remaining sediment to a standard depth (usually 2.0 inches [50 mm] or 3.9 inches [100 mm]) by repeatedly digging and stirring (a railroad spike is useful for this). The invertebrates and lighter debris then will be carried into the net. The top of the net should be tipped downstream until a 45° angle is formed with the streambed and the sampler quickly removed from the water. The net should be dipped several times in the stream to wash the contents to the bottom, but workers must be careful not to submerge the net opening. Net contents should then be transferred to a sample container. A net or shallow pan should be placed beneath the container to catch any spillage. The net and its seams should be carefully checked for adhering specimens.

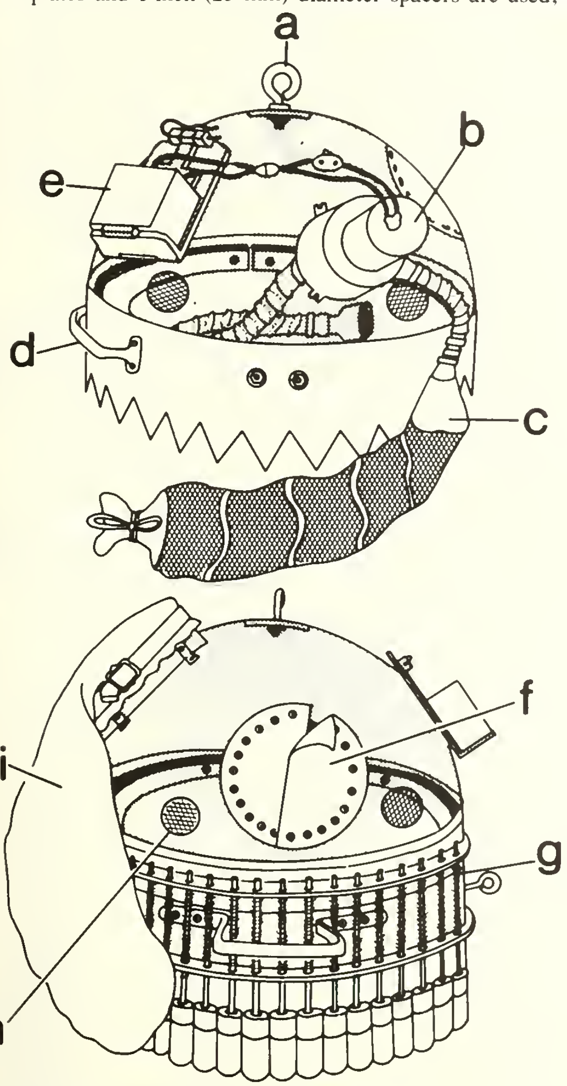



**Figure 26. — Dome sampler with serrated band (rear view) and polyurethane cylinder band (side view): (a) eye bolt, (b) bilge pump, (c) net bag, (d) handle, (e) battery, (f) armhole cover, (g) self-adjusting contour rod, (h) screened port, and (i) rock bag. (From Gale and Thompson [1975] with the authors' permission.)**

The samples should be preserved in 70 percent ethanol or 2 percent formaldehyde solution (5 percent formalin), and a volume of preservative at least equal to the volume of organic material added to insure adequate preservation. The containers should be filled to reduce damage to the macroinvertebrate specimens. Workers should use waterproof label paper or other material that will not deteriorate in water and a soft lead pencil or waterproof ink for identifying the collections. Label information should include location, habitat, and date of collection. Such additional information as sampling conditions, type of sampling device and mesh size, and name of the collector should be entered in a bound field notebook. The label should be placed inside the sample container; a duplicate label on the outside of the container provides added insurance that the information will not be lost and saves time in subsequent handling of samples.

## Sample Processing

Preprocessing reduces weight and bulk and prevents destruction of invertebrates from grinding by sediment. The sample should be placed in a large bucket or tray. Add water and swirl or stir the contents of the container to suspend the organic material. The suspension should be poured through the collecting net so that the heavier inorganic sediments will be left behind. This process should be repeated until no additional organic debris enters the net. The inorganic residue should be spread in a white tray and flooded with water. Such specimens as stone-cased caddisflies, mollusks, or planarians that have withstood the washing process should be examined and removed with forceps. The sediments should be discarded and the remainder preserved.

Whether the preprocessing step is done in the field or in the laboratory, the next step is to process the sample through a series of steps that ultimately will yield the raw data of the macroinvertebrate phase of the study:

1. Remove the organisms from the organic debris.
2. Sort them into groups of look-alikes (coarse sorting).
3. Identify the individual specimens to the taxonomic level desired and sort the look-alike groups into these categories (fine sorting).
4. Count and/or weigh the contents of each category and enter the values onto data forms.

Trays with white background or light transmitted from below should be used for removing the macroinvertebrates from the remaining organic matter. A large, low power (3X), illuminated magnifier is helpful at this stage. Only very small amounts (approximately a heaping tablespoonful) of material should be placed into a 15.7- by 9.8- by 2.0-inch tray (400- by 250- by 50-mm) about one-third full of water. For samples containing large numbers of organisms, processing time can be substantially reduced if the samples are subdivided before sorting. Details of two possible subsampling procedures are given by Weber (1973) and Waters (1969). Separation of invertebrates from plant and inorganic debris may be facilitated by flotation (Anderson 1959), differential staining (Mason and Yevich 1967), or a combination of these procedures (Lackey and May 1971).

As organisms are picked from the debris, they should be coarse-sorted into major groups and placed into leakproof vials filled with preservative (16.9 ounces [500 ml] 70 percent ethanol plus 0.3 ounce [10 ml] formalin [40 percent formaldehyde solution] plus 0.2 ounce [5 ml] glycerin) and the vials labeled. All vials from a sample should be kept together in a suitable container until processing is completed. A record should be kept of which worker sorted the sample.

The taxonomic level to which macroinvertebrates are identified depends on project objectives and available resources. But, except in cases of severe environmental disturbance, most situations needing assessment require identification to genus or species. The taxonomic level to which identifications are carried in each taxon should be constant throughout a particular study. The accuracy of identification depends on the experience and skill of the investigator and the availability of taxonomic literature. Basic sources of information include books by Edmondson (1958), Edmunds and others (1976), Pennak (1978), Usinger (1956), and Wiggins (1977) and the literature cited in these publications. Most identifications to family and genus can be made with the aid of a 5 to 50X stereoscopic microscope; those identifications to species often require a compound microscope. Maximum counting efficiency is at 25X magnification with transmitted light (Frost 1971).

Biomass measurements can be obtained by drying the organisms at 221° F (105° C) for at least 4 hours and then weighing them. Ash-free dry mass can be obtained by incinerating the material at 1022° F (550° C) for 1 hour, cooling in a dessicator, and calculating the difference between initial (dry) and final (ash) weights.

## Data Treatment and Interpretation

The treatment and interpretation of data obtained from macroinvertebrate collections is as much an art as it is a science and a detailed understanding of benthic invertebrate ecology is advisable. Basic information sources include books by Hellawell (1978), Hynes (1970, 1971), and Mackenthun (1969).

In the material that follows, we provide a synopsis of the principal methods used to analyze benthic macroinvertebrate data and information to guide interpretation of the results. However, the presentation is necessarily brief in keeping with the purposes of this manual. The nonspecialist should proceed with caution and should supplement the information provided by reference to the specific citations given or seek the aid of a competent professional.

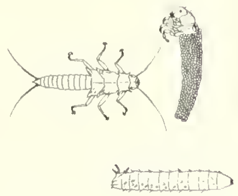
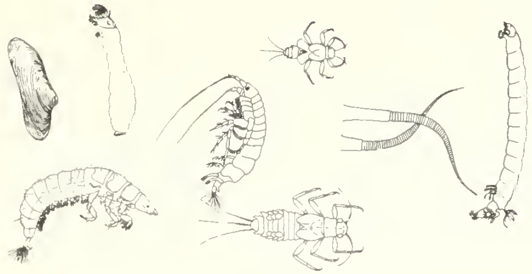
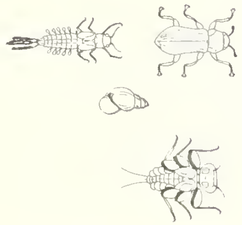
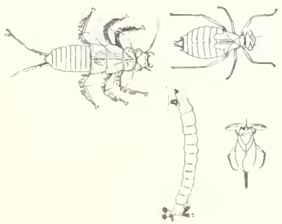
**Table 13.** — Mean standing crops of benthic macroinvertebrates in some Rocky Mountain streams as ash-free dry mass

| Stream | Location | $\bar{x}$ numbers/m² | $\bar{x}$ biomass/m² | Reference |
|---|---|---|---|---|
| | | | *Grams* | |
| Firehole River | Wyoming | 940 | | Armitage 1958 |
| Unnamed Springbrook | Colorado | | | |
| Station 5 | | 1,700 | 34.7 (wet weight) | |
| Station 4 | | 4,100 | 136.9 (wet weight) | Ward and Dufford 1979 |
| Mink Creek (1968-69 study) | Idaho | 6,900 | 10.8 (ash-free dry mass) | Minshall 1981 |
| Strawberry River | Utah | 8,800 | | Payne 1979 |
| Mink Creek (1969-70 study) | Idaho | 21,000 | 26.5 (ash-free dry mass) | Minshall 1981 |

**Table 14.** — Composition (percent of total numbers) of macroinvertebrate communities in some Rocky Mountain streams (Andrews and Minshall 1979)

| Stream | Location | Ephemeroptera | Trichoptera | Diptera | Plecoptera | Others |
|---|---|---|---|---|---|---|
| Morrell Creek | Montana | 65.0 | 4.4 | | 14.5 | [1]16.0 |
| Deer Creek | Utah | 63.9 | 17.9 | 12.3 | 2.2 | 3.4 |
| Little Lost River | Idaho | 61.5 | 14.4 | 10.3 | 12.4 | 1.4 |
| Trail Creek | Idaho | 52.0 | 6.0 | 16.0 | 6.0 | 20.0 |
| Pine Creek | Idaho | 48.0 | 18.0 | 9.0 | 7.0 | 18.0 |
| Mink Creek | Idaho | 46.5 | 9.9 | 13.0 | 12.2 | 18.4 |
| Viviana Park Creek | Utah | 43.5 | 5.7 | 14.4 | 26.8 | 9.6 |
| Bridger Creek | Montana | 9.2 | 71.9 | 12.2 | 1.7 | 5.0 |
| Aspen Grove Creek | Utah | 8.9 | 56.9 | 5.3 | 11.4 | 15.5 |
| Madison River | Montana | 22.5 | 35.4 | 23.8 | 1.8 | 16.5 |
| Provo River | Utah | 23.2 | 28.6 | 21.1 | 13.7 | 13.4 |
| Portneuf River | Idaho | 3.0 | 10.8 | 72.0 | 0.2 | 14.0 |

[1]Includes Diptera.

| General category based on feeding mechanism | General particle size range of food | Subdivision based on feeding mechanisms | Subdivision based on dominant food | North American aquatic insect taxa containing predominant examples |
|---|---|---|---|---|
| **SHREDDERS**  | *Microns* < 10³ | Chewers and miners | Herbivores, living vascular plant tissue | Trichoptera (Phryganeidae, Leptoceridae)<br>Lepidoptera<br>Coleoptera (Chrysomelidae)<br>Diptera (Chironomidae, Ephydridae) |
| | | Chewers and miners | Detritivores (large particle detritivores): decomposing vascular plant tissue | Plecoptera (Filipalpia)<br>Trichoptera (Limnephilidae, Lepidostomatidae)<br>Diptera (Tipuiidae, Chironomidae) |
| **COLLECTORS**  | < 10³ | Filter or suspension feeders | Herbivore-detritivores: living algal cells, decomposing organic matter | Ephemeroptera (Siphlonuridae)<br>Trichoptera (Philopotamidae, Psychomyiidae, Hydropsychidae, Brachycentridae)<br>Lepidoptera<br>Diptera (Simuliidae, Chironomidae, Culicidae) |
| | | Sediment or deposit (surface) feeders | Detritivores (fine particle detritivores): decomposing organic matter | Ephemeroptera (Caenidae, Ephemeridae, Leptophlebiidae)<br>Trichoptera (Glossosomatidae, Helicopsychidae, Molannidae, Odontoceridae, Goerinae)<br>Lepidoptera<br>Coleoptera (Elmidae, Psephenidae)<br>Diptera (Chironomidae, Tabanidae) |
| **SCRAPERS**  | < 10³ | Mineral scrapers | Herbivores: algae and associated material (periphyton) | Ephemeroptera (Heptageniidae, Baetidae, Ephemerellidae)<br>Trichoptera (Glossosomatidae, Helicopsychidae, Molannidae, Odontoceridae, Goerinae)<br>Lepidoptera<br>Coleoptera (Elmidae, Psephenidae)<br>Diptera (Chironomidae, Tabanidae) |
| | | Organic scrapers | Herbivores: algae and associated material (periphyton) | Ephemeroptera (Caenidae, Leptophlebiidae, Heptageniidae, Baetidae)<br>Hemiptera (Corixidae)<br>Trichoptera (Leptoceridae)<br>Diptera (Chironomidae) |
| **PREDATORS**  | > 10³ | Engulfers | Carnivores: whole animals (or parts) | Odonata<br>Plecoptera (Setipalpia)<br>Megaloptera<br>Trichoptera (Rhyacophillidae, Polycentropidae, Hydropsychidae)<br>Coleoptera (Dytiscidae, Gyrinnidae)<br>Diptera (Chironomidae) |
| | | Piercers | Carnivores: cell and tissue fluids | Hemiptera (Belastomatidae, Nepidae, Notonectidae, Naucoridae) Diptera (Rhagionidae) |

### Abundance

The raw data obtained from the processing of stream-collected macroinvertebrate samples can be analyzed in a variety of ways to enhance informational value to an aquatic specialist or resource manager. As a first step in data analysis, the values (numbers or biomass) for each taxon and for all taxa combined should be tabulated and the means and variances determined for each station. Expression of these results as amounts per sampler or amounts per unit area provides the basis for comparisons between stations, times, streams, and published works. Comparisons enable aquatic ecologists to determine such things as the biological condition of the stream, the extent to which the stream has been impacted by environmental disturbance, and the potential for stream improvement. Reliable published values for evaluations of this sort are few. But, it appears for example, that total numbers of organisms in most undisturbed Rocky Mountain streams can be expected to lie between 93 and 930/ft$^2$ (1 000 and 10 000/m$^2$ (table 13) depending on nutrient levels, current velocity, substratum type, and other factors controlling overall stream productivity.

In addition to evaluating the absolute quantities of organisms present, it is important to know the relative abundance of each taxon to establish the extent to which the macroinvertebrate community is considered to be in biological balance. For example, data for a number of Rocky Mountain streams (table 14) show that under normal circumstances mayflies (Ephemeroptera) or caddisflies (Trichoptera) would be expected to be numerically predominant. The predominance of true flies (Diptera) in the Portncuf River, Idaho, supports the contention (Minshall and Andrews 1973) that it is polluted. See appendix 7 for tolerance quotients of macroinvertibrates.

### Richness

Another valuable indicator of macroinvertebrate community status is the total number of taxa (preferably species) present at a specific site on a given sampling date or on an annual basis. The number of taxa is termed richness and can be expected to decrease with either natural or man-caused environmental stress. In general, for unperturbed Idaho streams, it has been estimated that the number of persistent species of macroinvertebrates (exclusive of Chironomidae) occurring during the year will be between 50 and 65.

### Functional Feeding Group Status

Cummins (1973, 1974) has advocated the organization of macroinvertebrate data into functional categories based on feeding behavior as a means of gaining insight into ecosystem status. A general scheme for placement into appropriate feeding categories is given in table 15 and additional information is summarized by Merritt and Cummins (1978). Although the approach shows considerable promise, relatively little use has been made of it to date (Hawkins and Sedell 1980; Minshall 1981). However, caution should be used in placing macroinvertebrates into functional categories using published information, such as table 13, as many of these are crude approximations and conditions may vary among streams and times of year.

## Biological Indexes

The complexity of data on benthic macroinvertebrate communities has led to the use of various biological indexes in order to provide fuller undestanding of the data and/or to simplify their presentation and interpretation. However, whatever valuable adjunct these indexes serve, they should not be used as substitutes for the basic information on abundance and biomass described above. A particularly lucid explanation of the uses and limitations of biological indexes is given by Warren (1971).

Two approaches have been used. One involves mathematical manipulation of information on the number of individuals per taxon (abundance) and the number of taxa present in a community (richness) and is termed a diversity index. Since environmental stress frequently reduces community diversity, such indexes are potentially valuable devices, provided that the change in value of the index is related to the intensity of the disturbance. The second approach attempts to incorporate information on the environmental requirements of the species involved and is termed a biotic index.

### Diversity Index

The most widely used community diversity index is that of Shannon-Wiener (Wilhm 1968; Wilhm and Dorris 1968) and is calculated as:

$$H' = -\sum_{i=1}^{s} (n_i/n)\log(n_i/n)$$

where n = the total number of individuals of all taxa, $n_i$ = the number of individuals in the ith taxon, and s is the total number of taxa in the community. The base of the logarithm must be specified and usually is $\log_2$. The advantages of this index over other possible diversity indexes include: (a) relative abundances of the different taxa are taken into account; (b) it is relatively independent of sample size; and (c) the values are dimensionless and therefore are not dependent on the unit of measurement used.

In general, values ($\log_2$) of H′ less than 3 are found for benthic invertebrates in areas of clean water, values from 1 to 3 in areas of moderate pollution, and values less than 1 in heavily polluted

**Table 16.** — Shannon-Weiner diversity (H′) and equitability (e) for some Rocky Mountain streams

| Stream | Location | H′ | e | Source |
|---|---|---|---|---|
| Unnamed Springbrook | Colorado | 1.8-3.7 | 0.1-0.5 | Ward and Dufford 1979 |
| Mink Creek | Idaho | 3.7 | 0.3 | Minshall 1981 |
| Horse Creek | Idaho | 2.8-3.2 | | Newton and Rabe 1977 |
| Upper Blackfoot River | Idaho | 2.6-4.3 | 0.2-0.7 | Platts and Andrews 1980 |
| Portneuf River (Stations 2, 5, 8, 9b) | Idaho | 1.3-2.6 | 0.1-0.4 | Minshall and Andrews 1973 |

**Table 17.** — The hypothetical number of species (s*) for various values of H′ (Lloyd and Ghelardi 1964)

| s* | H′ | s* | H′ | s* | H′ | s* | H′ |
|---|---|---|---|---|---|---|---|
| 1 | 0.0000 | 51 | 5.0941 | 102 | 6.0792 | 205 | 7.0783 |
| 2 | 0.8113 | 52 | 5.1215 | 104 | 6.1069 | 210 | 7.1128 |
| 3 | 1.2997 | 53 | 5.1485 | 106 | 6.1341 | 215 | 7.1466 |
| 4 | 1.6556 | 54 | 5.1749 | 108 | 6.1608 | 220 | 7.1796 |
| 5 | 1.9374 | 55 | 5.2009 | 110 | 6.1870 | 225 | 7.2118 |
| 6 | 2.1712 | 56 | 5.2264 | 112 | 6.2128 | 230 | 7.2434 |
| 7 | 2.3714 | 57 | 5.2515 | 114 | 6.2380 | 235 | 7.2743 |
| 8 | 2.5465 | 58 | 5.2761 | 116 | 6.2629 | 240 | 7.3045 |
| 9 | 2.7022 | 59 | 5.3004 | 118 | 6.2873 | 245 | 7.3341 |
| 10 | 2.8425 | 60 | 5.3242 | 120 | 6.3113 | 250 | 7.3631 |
| 11 | 2.9701 | 61 | 5.3476 | 122 | 6.3350 | 255 | 7.3915 |
| 12 | 3.0872 | 62 | 5.3707 | 124 | 6.3582 | 260 | 7.4194 |
| 13 | 3.1954 | 63 | 5.3934 | 126 | 6.3811 | 265 | 7.4468 |
| 14 | 3.2960 | 64 | 5.4157 | 128 | 6.4036 | 270 | 7.4736 |
| 15 | 3.3899 | 65 | 5.4378 | 130 | 6.4258 | 275 | 7.5000 |
| 16 | 3.4780 | 66 | 5.4594 | 132 | 6.4476 | 280 | 7.5259 |
| 17 | 3.5611 | 67 | 5.4808 | 134 | 6.4691 | 285 | 7.5513 |
| 18 | 3.6395 | 68 | 5.5018 | 136 | 6.4903 | 290 | 7.5763 |
| 19 | 3.7139 | 69 | 5.5226 | 138 | 6.5112 | 295 | 7.6008 |
| 20 | 3.7846 | 70 | 5.5430 | 140 | 6.5318 | 300 | 7.6250 |
| 21 | 3.8520 | 71 | 5.5632 | 142 | 6.5521 | 310 | 7.6721 |
| 22 | 3.9163 | 72 | 5.5830 | 144 | 6.5721 | 320 | 7.7177 |
| 23 | 3.9779 | 73 | 5.6027 | 146 | 6.5919 | 330 | 7.7620 |
| 24 | 4.0369 | 74 | 5.6220 | 148 | 6.6114 | 340 | 7.8049 |
| 25 | 4.0937 | 75 | 5.6411 | 150 | 6.6306 | 350 | 7.8465 |
| 26 | 4.1482 | 76 | 5.6599 | 152 | 6.6495 | 360 | 7.8870 |
| 27 | 4.2008 | 77 | 5.6785 | 154 | 6.6683 | 370 | 7.9264 |
| 28 | 4.2515 | 78 | 5.6969 | 156 | 6.6867 | 380 | 7.9648 |
| 29 | 4.3004 | 79 | 5.7150 | 158 | 6.7050 | 390 | 8.0022 |
| 30 | 4.3478 | 80 | 5.7329 | 160 | 6.7230 | 400 | 8.0386 |
| 31 | 4.3936 | 81 | 5.7506 | 162 | 6.7408 | 410 | 8.0741 |
| 32 | 4.4381 | 82 | 5.7681 | 164 | 6.7584 | 420 | 8.1087 |
| 33 | 4.4812 | 83 | 5.7853 | 166 | 6.7757 | 430 | 8.1426 |
| 34 | 4.5230 | 84 | 5.8024 | 168 | 6.7929 | 440 | 8.1757 |
| 35 | 4.5637 | 85 | 5.8192 | 170 | 6.8099 | 450 | 8.2080 |
| 36 | 4.6032 | 86 | 5.8359 | 172 | 6.8266 | 460 | 8.2396 |
| 37 | 4.6417 | 87 | 5.8524 | 174 | 6.8432 | 470 | 8.2706 |
| 38 | 4.6792 | 88 | 5.8687 | 176 | 6.8596 | 480 | 8.3009 |
| 39 | 4.7157 | 89 | 5.8848 | 178 | 6.8758 | 490 | 8.3305 |
| 40 | 4.7513 | 90 | 5.9007 | 180 | 6.8918 | 500 | 8.3596 |
| 41 | 4.7861 | 91 | 5.9164 | 182 | 6.9076 | 550 | 8.4968 |
| 42 | 4.8200 | 92 | 5.9320 | 184 | 6.9233 | 600 | 8.6220 |
| 43 | 4.8532 | 93 | 5.9474 | 186 | 6.9388 | 650 | 8.7373 |
| 44 | 4.8856 | 94 | 5.9627 | 188 | 6.9541 | 700 | 8.8440 |
| 45 | 4.9173 | 95 | 5.9778 | 190 | 6.9693 | 750 | 8.9434 |
| 46 | 4.9483 | 96 | 5.9927 | 192 | 6.9843 | 800 | 9.0363 |
| 47 | 4.9787 | 97 | 6.0075 | 194 | 6.9992 | 850 | 9.1236 |
| 48 | 5.0084 | 98 | 6.0221 | 196 | 7.0139 | 900 | 9.2060 |
| 49 | 5.0375 | 99 | 6.0366 | 198 | 6.0284 | 950 | 9.2839 |
| 50 | 5.0661 | 100 | 6.0510 | 200 | 6.0429 | 1000 | 9.3578 |

waters (Mathis 1968; Wilhm and Dorris 1968; Wilhm 1970; Lloyd and Ghelardi 1964). Published values for Rocky Mountain streams (table 16) are sparse, but generally approach or exceed 3.

It also may be of interest to calculate the equitability or evenness of allotment of individuals among taxa. Equitability (e) can be calculated in several ways but a common method is as follows:

$e = \frac{s^*}{s}$ where s is the number of species actually collected and s* is a hypothetical number of species and may be obtained from table 16 for any given value of H′. Equitability is thought to be more sensitive than H′ to slight or moderate levels of degradation (Weber 1973). Values range between 0 and 1. Those values less than 0.5 are considered to characterize macroinvertebrate communities in relatively natural streams (Weber 1973). The few values published for Rocky Mountain streams range from 0.1 to 0.5 (table 17).

Redundancy (r) is a measure of the dominance of one or more taxa and is inversely proportional to the variety of species. It is calculated as:

$$r = \frac{H'_{max} - H'}{H'_{max} - H'_{min}}.$$

The theoretical maximum diversity and the minimum diversity, $H'_{max}$ and $H'_{min}$, and are calculated as:

$$H'_{max} = \frac{\log_2 n! - s \log_2 \frac{n}{s}!}{n}$$

$$H'_{min} = \frac{\log_2 n! - \log_2 (n+s+1)!}{n}$$

The Shannon-Weiner Diversity Index and other measures derived from it have been widely criticized as inappropriate for detecting the impact of pollution and other types of environmental stress (for example, Peet 1974, 1975; Cook 1976; Zand 1976; Pielou 1975, 1977). Thus, the procedure should be used with caution if at all.

**Biotic Indexes**

Of the various biotic indexes that have been proposed for use with macroinvertebrates, two deserve attention here: the Biotic Condition Index and the Chandler Biotic Score. Each approach has its shortcomings. The BCI does not include a measure of relative abundance, while the CBS is based on subjective tolerance ratings. In practice, both systems are subject to user biases and previous experience, especially when taxa are encountered that were not included in the original system and when species within an order, family, or genus have quite different tolerances.

The Biotic Condition Index (Winget and Mangum 1979) currently is being advocated for use by Forest Service (Intermountain Region) personnel. Other than the data on which the Index was developed, no other results of its use have been published.

The BCI incorporates stream habitat (gradient, substrate composition), water quality (alkalinity, sulfate), and environmental tolerances of aquatic macroinvertebrate species. It is a function of a Predicted Community Tolerance Quotient ($CTQ_p$) divided by the Actual Community Tolerance Quotient ($CTQ_a$). The tolerance quotient (TQ) is the product of values derived from the taxon's tolerance to levels of alkalinity and sulfate plus its selectivity for or against fine substrate materials and low stream gradients. Values range from 2 to slightly greater than 100 with the larger values indicating greater tolerance. The TQ's have been determined for 54 taxa and values assigned to an additional 317 (appendix 7). The $CTQ_p$ is the mean of the TQ's for a predicted macroinvertebrate community. To obtain a $CTQ_p$ for a particular stream segment, the station is classified according to the criteria given above (appendix 8). A $CTQ_a$ is simply a mean of the TQ's of the macroinvertebrates collected from any station on any given date. The Biotic Condition Index is calculated as:

$$BCI = \frac{CTQ_p}{CTQ_a} \times 100.$$

Values are expressed as percent of expected value.

In the Chandler Biotic Score system (Chandler 1970), the taxa are rated from intolerant to highly tolerant. The intolerant species have values near 100 and the highly tolerant species have values near 0. The score is adjusted over a 10-point range depending on relative abundance. In the original system, the numerical value for

**Table 18.** — Comparison of various indexes of pollution for selected stations on the Portneuf River (Minshall and Andrews 1973); Biotic Condition Index and Chandler Biotic Score values were obtained from Frazier and others (1980)

| Indexes | Station 2 | Station 5 | Station 8 | Station 9b |
|---|---|---|---|---|
| Abundance ($\bar{x}$ number/sampler) | 373 | 2,691 | 63 | 32 |
| Richness | 28 | 26 | 13 | 10 |
| Diversity (H′) | 2.6 | 1.3 | 1.9 | 1.6 |
| Equitability (e) | .3 | .1 | .4 | .4 |
| BCI $\bar{x}$ (n=5) SD | 117.2 (±4.8) | 107.0 (±8.1 | 61.2 (±1.1) | 64.4 (±2.6) |
| CBS | 58.6 | 53.6 | 48.5 | 38.6 |

each taxon was simply added to the summed values for all taxa, but this gave a wide range of scores from less than 100 to several thousand. Cook (1976) modified the system by dividing the score by the number of taxa. This produced a linear scale of values between 0 and 100, decreasing with an increase in environmental stress. The modified Chandler Biotic Score is obtained by assigning each taxon (s) in a sample a rating (R) based on its taxonomic status and relative abundance (appendix 9). These ratings are then summed and divided by the total number of taxa present:

$$CBS = \frac{\sum_{i=1}^{s} R_i}{s}.$$

**Comparison of Indexes**

The different indexes discussed above were calculated for several stations on the Portneuf River, Idaho, subjected to varying but generally increasing degrees of environmental stress. The results (table 18) are based on data given by Minshall and Andrews (1973). The indexes all show the same basic trend suggesting a progressive decrease in water quality proceeding downstream from stations 2 through 9b. The principal variant is H′, which was strongly influenced by a disproportionately large number of the dipteran *Simulium* (76 percent of total). The BCI values closely follow those of richness and suggest a much larger deterioration in water quality at the two downstream stations than is reflected by the CBS values. On the other hand, the BCI values indicate that the two upper stations are at or near their potential while the CBS values show that considerable deterioration has occurred even at those sites. To this extent, the H′ and CBS values are in accord. Based on the data currently available, it is not possible to conclusively determine which biotic index best reflects actual conditions. Stations 2 and 5 are known to be impacted upstream by various agricultural practices (xylene control of macrophytes, grazing, and irrigation uses). But, on the other hand, the Portneuf River in the vicinity of station 2 is considered a "blue-ribbon" trout stream. Neither index shows much of an impact of dewatering by irrigation diversion at station 5, yet the quality of that area as a summer fishery habitat clearly is degraded by this activity.

## CONCLUSIONS

Much of the literature on evaluation of the stream environment lies hidden in unpublished reports. In addition, when a resouce manager attacks a stream problem to determine its solution, it is necessary to start from scratch. The attributes to be measured must be selected and procedures devised. Sometimes these are successful, but many times they are not. Progress has largely been by trial and error with no source of standard measures and procedures available for guidance.

This manual is an attempt to draw together and describe a comprehensive set of routine measurements for use by resource managers in evaluating and/or monitoring conditions in and adjacent to streams. In addition, we have tried wherever possible to evaluate and assess the reliability attainable with the various measurements. It has not been possible to do this in all cases, but we hope to move closer to that goal in subsequent versions of this manual. Other manuals on flowing water methods are available to evaluate: stream morphology (USDA Forest Service 1975); streamflow effects (Stalnaker and Arnette 1976); stream bank stability (Cooper 1976); and general stream conditions (Duff and Cooper 1978). But, these deal with isolated aspects of the stream-riparian milieu and exclude the biotic component of lotic ecosystems. In addition, they fail to provide alternative approaches from which to select the most appropriate measurements for a given situation and they do not indicate the limitations of the recommended procedures. Others (Rickert and others 1978; USDI Bureau of Land Management 1973) have suggested a subjective approach to stream evaluation largely for purposes of economy. These methods may work for the specific purpose they were designed, but they are often inadequate if the objectives change. The underlying problem with these types of intuitive methods is that from different perspectives, which cause different interpretations, the same stream can be evaluated differently.

Although this report places measures of reliability on many of the attributes, it does not give the reliability that can be expected from the complete family of attributes selected to characterize stream conditions. This can come with experience only and will depend on the objectives of the study. Much thought must be given to selecting the family of attributes to be measured for they must cover those states or changes in states that actually control the density and composition of the populations of interest. The biotic resource itself plays an important part in becoming a component in the family of attributes. Not only does it help to ascertain what the enviromental conditions are at the time of sampling but also what they were prior to sampling.

Stream evaluation methods are not perfect, nor will they be perfect in the near future. They will not do all things for all purposes. Therefore, such methods need constant refinement and new and better techniques must be developed. In addition, the reaction of biotic resources to environmental changes must be defined. These goals are some distance off, but we hope this manual hastens their accomplishment.

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# APPENDIX 1

## The t Distribution

Table 19. — Student's t distribution[1]

| v[2] | 0.60 | 0.75 | 0.90 | P[3] 0.95 | 0.975 | 0.99 | 0.995 | 0.9995 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.325 | 1.000 | 3.078 | 6.314 | 12.706 | 31.821 | 63.657 | 636.619 |
| 2 | .289 | .816 | 1.886 | 2.920 | 4.303 | 6.965 | 9.925 | 31.598 |
| 3 | .277 | .765 | 1.638 | 2.353 | 3.182 | 4.541 | 5.841 | 12.941 |
| 4 | .271 | .741 | 1.533 | 2.132 | 2.776 | 3.747 | 4.604 | 8.610 |
| 5 | .267 | .727 | 1.476 | 2.015 | 2.571 | 3.365 | 4.032 | 6.859 |
| 6 | .265 | .718 | 1.440 | 1.943 | 2.447 | 3.143 | 3.707 | 5.959 |
| 7 | .263 | .711 | 1.415 | 1.895 | 2.365 | 2.998 | 3.499 | 5.405 |
| 8 | .262 | .706 | 1.397 | 1.860 | 2.306 | 2.896 | 3.355 | 5.041 |
| 9 | .261 | .703 | 1.383 | 1.833 | 2.262 | 2.821 | 3.250 | 4.781 |
| 10 | .260 | .700 | 1.372 | 1.812 | 2.228 | 2.764 | 3.169 | 4.587 |
| 11 | .260 | .697 | 1.363 | 1.796 | 2.201 | 2.718 | 3.106 | 4.437 |
| 12 | .259 | .695 | 1.356 | 1.782 | 2.179 | 2.681 | 3.055 | 4.318 |
| 13 | .259 | .694 | 1.350 | 1.771 | 2.160 | 2.650 | 3.012 | 4.221 |
| 14 | .258 | .692 | 1.345 | 1.761 | 2.145 | 2.624 | 2.977 | 4.140 |
| 15 | .258 | .691 | 1.341 | 1.753 | 2.131 | 2.602 | 2.947 | 4.073 |
| 16 | .258 | .690 | 1.337 | 1.746 | 2.120 | 2.583 | 2.921 | 4.015 |
| 17 | .257 | .689 | 1.333 | 1.740 | 2.110 | 2.567 | 2.898 | 3.965 |
| 18 | .257 | .688 | 1.330 | 1.734 | 2.101 | 2.552 | 2.878 | 3.922 |
| 19 | .257 | .688 | 1.328 | 1.729 | 2.093 | 2.539 | 2.861 | 3.883 |
| 20 | .257 | .687 | 1.325 | 1.725 | 2.086 | 2.528 | 2.845 | 3.850 |
| 21 | .257 | .686 | 1.323 | 1.721 | 2.080 | 2.518 | 2.831 | 3.819 |
| 22 | .256 | .686 | 1.321 | 1.717 | 2.074 | 2.508 | 2.819 | 3.792 |
| 23 | .256 | .685 | 1.319 | 1.714 | 2.069 | 2.500 | 2.807 | 3.767 |
| 24 | .256 | .685 | 1.318 | 1.711 | 2.064 | 2.492 | 2.797 | 3.745 |
| 25 | .256 | .684 | 1.316 | 1.708 | 2.060 | 2.485 | 2.787 | 3.725 |
| 26 | .256 | .684 | 1.315 | 1.706 | 2.056 | 2.479 | 2.779 | 3.707 |
| 27 | .256 | .684 | 1.314 | 1.703 | 2.052 | 2.473 | 2.771 | 3.690 |
| 28 | .256 | .683 | 1.313 | 1.701 | 2.048 | 2.467 | 2.763 | 3.674 |
| 29 | .256 | .683 | 1.311 | 1.699 | 2.045 | 2.462 | 2.756 | 3.659 |
| 30 | .256 | .683 | 1.310 | 1.697 | 2.042 | 2.457 | 2.750 | 3.646 |
| 40 | .255 | .681 | 1.303 | 1.684 | 2.021 | 2.423 | 2.704 | 3.551 |
| 60 | .254 | .679 | 1.296 | 1.671 | 2.000 | 2.390 | 2.660 | 3.460 |
| 120 | .254 | .677 | 1.289 | 1.658 | 1.980 | 2.358 | 2.617 | 3.373 |
| ∞ | .253 | .674 | 1.282 | 1.645 | 1.960 | 2.326 | 2.576 | 3.291 |

[1]Reprinted with permission from *Statistical Tables for Biological, Agricultural, and Medical Research* (6th ed., 1974) written by Sir Ronald A. Fisher and Dr. Frank Yates and published by Longman Group Ltd., London (previously published by Oliver & Boyd Ltd., Edinburgh).

[2]V = degrees of freedom.

[3]P = probability.

# APPENDIX 2
## Transect Spacing

For general, broad-base planning purposes or general studies that cover large land areas and do not need refined information, the 200-ft (61-m) transect spacing would be adequate for making general interpretations from the data collected. To determine habitat conditions for making project decisions at the project level (for example, the Ranger District level), the 50-ft (15.2 m) spacing is probably adequate. For research purposes or for intensive studies, such as determining influences from point source pollution or for answers needing high accuracy in the results, the transects should probably be no more than 10 ft (3.0 m) apart.

To determine the reliability of different transect spacings, four streams were selected for testing. Two were in the Blackfoot River drainage of eastern Idaho and two in the central Idaho Batholith. At selected sites on each stream, 181 transects were set in at 10-ft (3.0-m) intervals. The habitat attribute means, standard deviation (S) around the mean, and auto correlation coefficients (AC) were calculated at transect interval spacings from 10 to 200 ft (3.1 to 61 m) over the same reach of stream. Thus, at the 10-ft spacings, 181 data entries were used to determine the mean of each habitat variable. At 50-ft spacings, only 36 data entries were used. The means derived from the 10-ft spacing were assumed to be the true means.

### Blackfoot River Drainage Tests

In the Blackfoot River drainage, those habitat measurements (table 20) having low values or those conditions that seldom occur in the study area, such as large boulder (>2 ft [>0.61 m]) in the channel, were often missed at spacings above 30 ft (9.1 m).

**Table 20.** — Means and standard deviations (S) for percent channel composed of large boulders for selected transect spacings in Diamond Creek, Idaho

| | Spacing | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 |
| | Feet | | | | |
| Mean | 0.08 | 0.07 | 0.01 | 0.0 | 0.0 |
| S | 0.06 | 0.06 | 0.09 | 0.0 | 0.0 |

The standard deviations in most habitat measurements increased as transect spacing increased, whereas the autocorrelation (correlation between individual values of a variable) coefficients decreased. The greatest differences occurred in stream width, with means about 100 percent greater at 50-ft (15.2-m) spacing than at the 10-ft (3.0-m) spacing (table 21).

**Table 21.** — Means, standard deviations (S), and autocorrelations (AC) for stream width for selected transect spacings in Diamond Creek

| | Spacing | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 |
| | Feet | | | | |
| Mean | 7.53 | 7.57 | 7.97 | 7.46 | 14.46 |
| S | 3.18 | 3.63 | 4.32 | 6.04 | 4.94 |
| AC | 0.28 | 0.18 | 0.24 | 0.15 | 0.20 |

Habitat measurement means tended to vary as spacing distance increased, especially after the 30-ft (9.1-m) spacing. A habitat variable mean derived from the largest (50-ft) (15.2-m) spacing, however, was often very close to the mean derived from the smallest (10-ft) (3.0-m) spacing (table 22).

**Table 22.** — Means, standard deviations (S), and autocorrelations (AC) for stream width for selected transect spacings in Angus Creek

| | Spacing | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 |
| | Feet | | | | |
| Mean | 16.56 | 16.33 | 16.28 | 16.33 | 16.86 |
| S | 5.90 | 6.27 | 5.83 | 5.88 | 5.65 |
| AC | .48 | .38 | .21 | .18 | .18 |

In Angus Creek, mean stream width and its standard deviation remained about the same as spacing increased, whereas the autocorrelation decreased. This shows that the variation of stream width between the individual transects increased as spacing increased and sample size decreased.

### Salmon River Drainage Tests

Stream reaches on Frenchman Creek and the South Fork Salmon River were studied each year from 1976 to 1980. Each reach covered 1,800 ft (548.6 m) of stream and was blanketed by 181 equal distance transects. The mean of each habitat variable was determined from transects spaced 10 ft (3.0 m), 20 ft (6.1 m), 30 ft (9.1 m), 40 ft (12.2 m), 50 ft (15.2 m), 100 ft (30.5 m) and 200 ft (61.0 m) apart. Again, as was the case in the Blackfoot River drainage, it was remarkable how often the mean derived from the 200-ft (61.0-m) spacing was about the same as the mean derived from the 10-ft (3.0-m) spacing. However, on certain habitat measurements the mean would be completely off target at the 200-ft (61.0-m) spacing.

As spacing between transects increased, the standard deviation and confidence intervals around the means increased. In measuring stream width over a 5-year period on the same reach in the South Fork Salmon River, confidence intervals around the means were about five times as wide at the 200-ft (61.0-m) spacing as at the 10-ft (3.0-m) spacing. In the Frenchman Creek reach, the confidence interval was two to three times as wide at the 200-ft (61.0-m) spacing. Stream depth also followed this pattern.

Percent riffle in the channel (table 23), because it varied considerably, was not determined with confidence when transect spacing exceeded 50 ft (15.2 m).

**Table 23.** — Means and percent confidence interval (CI) about the mean at the 95 percent confidence level for percent riffle in the South Fork Salmon River reach in 1980

| | Spacing | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 100 | 200 |
| | Feet | | | | | | | |
| Mean | 27 | 27 | 30 | 27 | 31 | 33 | 36 | 38 |
| CI | 16 | 23 | 28 | 32 | 38 | 37 | 44 | 53 |

# APPENDIX 2 (con.)

Some habitat variables, such as the pool quality rating (discussed later) were read quite accurately at the 200-ft (61.0-m) transect spacing (table 24). Confidence intervals, however, became much wider due mainly to the smaller sample size.

**Table 24.** — Means and percent confidence interval (CI) about the mean at the 95 percent confidence for pool quality in the Frenchman Creek reach in 1980

| | Spacing | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 100 | 200 |
| | *Feet* | | | | | | | |
| Mean | 3.9 | 4.0 | 4.0 | 4.1 | 4.0 | 3.9 | 4.1 | 4.0 |
| CI | 4 | 4 | 5 | 4 | 8 | 8 | 11 | 10 |

# APPENDIX 3

## Examples of Accuracy, Precision, and Confidence Intervals

**(Attribute Means from 1,800-ft [549-m] Study Reaches for One-Time Measurements)**

**Table 25.** — Accuracy, precision, and confidence interval for stream width

| Stream | Mean width | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Feet* | *± Percent* | | |
| Horton Creek | 4.2 | 6.6 | Good | Excellent |
| Gance Creek | 5.6 | 5.0 | Excellent | Good |
| Frenchman Creek | 11.5 | 5.8 | Good | Good |
| Johnson Creek | 9.5 | 5.1 | Good | Good |
| South Fork Salmon River | 15.6 | 4.7 | Excellent | Good |
| Elk Creek | 30.3 | 5.2 | Good | Good |

**Table 26.** — Accuracy, precision, and confidence intervals for stream depth

| Stream | Mean depth | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Feet* | *± Percent* | | |
| Horton Creek | 0.4 | 6.8 | Good | Excellent |
| Gance Creek | .2 | 9.2 | Good | Good |
| Frenchman Creek | .8 | 7.8 | Good | Good |
| Johnson Creek | .8 | 8.9 | Good | Good |
| South Fork Salmon River | .8 | 8.0 | Good | Good |
| Elk Creek | 1.1 | 8.3 | Good | Excellent |

**Table 27.** — Accuracy, precision, and confidence intervals for stream shore water depth

| Stream | Mean depth | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Feet* | *± Percent* | | |
| Horton Creek | 0.2 | 19.8 | Fair | Good |
| Gance Creek | .3 | 26.6 | Poor | Fair |
| Frenchman Creek | .5 | 13.2 | Fair | Fair |
| Johnson Creek | .3 | 16.5 | Fair | Fair |
| South Fork Salmon River | .5 | 10.6 | Good | Poor |
| Elk Creek | .3 | 12.9 | Fair | Good |

**Table 28.** — Accuracy, precision, and confidence intervals for percent pool

| Stream | Mean pool | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Percent* | *± Percent* | | |
| Horton Creek | 25.9 | 20.7 | Poor | Fair |
| Gance Creek | 34.4 | 13.5 | Fair | Fair |
| Frenchman Creek | 72.7 | 7.0 | Good | Poor |
| Johnson Creek | 76.3 | 6.1 | Good | Poor |
| South Fork Salmon River | 70.5 | 6.8 | Good | Poor |
| Elk Creek | 68.1 | 7.4 | Good | Poor |

**Table 29.** — Accuracy, precision, and confidence intervals for pool quality

| Stream | Mean pool quality | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | | *± Percent* | | |
| Horton Creek | 2.5 | 11.6 | Fair | Fair |
| Gance Creek | 2.2 | 10.3 | Fair | Poor |
| Frenchman Creek | 3.7 | 6.2 | Good | Poor |
| Johnson Creek | 3.7 | 7.5 | Good | Fair |
| South Fork Salmon River | 4.0 | 6.8 | Good | Fair |
| Elk Creek | 4.0 | 5.4 | Good | Good |

**Table 30.** — Accuracy, precision, and confidence intervals for percent riffle

| Stream | Mean riffle | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Percent* | *± Percent* | | |
| Horton Creek | 74.0 | 6.5 | Good | Fair |
| Gance Creek | 65.5 | 6.8 | Good | Poor |
| Frenchman Creek | 27.3 | 19.2 | Fair | Poor |
| Johnson Creek | 23.7 | 20.4 | Fair | Poor |
| South Fork Salmon River | 30.0 | 16.6 | Fair | Poor |
| Elk Creek | 30.3 | 5.2 | Good | Poor |

**Table 31.** — Accuracy, precision, and confidence intervals for sun angle

| Stream | Sun arc angle | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Degrees* | *± Percent* | | |
| Horton Creek | — | — | — | — |
| Gance Creek | — | — | — | — |
| Frenchman Creek | 122.4 | 1.5 | Excellent | Good |
| Johnson Creek | 148.2 | .4 | Excellent | Poor |
| South Fork Salmon River | 109.2 | 4.0 | Excellent | Excellent |
| Elk Creek | 163.0 | .6 | Excellent | Poor |

Table 32. — Accuracy, precision, and confidence intervals for streambank soil alteration

| Stream | | Streambank alteration | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|---|
| | | *Percent* | *± Percent* | | |
| Horton Creek | Natural | 8.9 | 12.0 | Fair | Good |
| | Artificial | 22.7 | 8.8 | Good | Good |
| Gance Creek | Natural | 31.0 | 6.0 | Good | Fair |
| | Artificial | 13.3 | 13.5 | Fair | Poor |
| Frenchman Creek | Natural | 20.7 | 11.5 | Fair | Fair |
| | Artificial | 5.0 | 24.6 | Poor | Poor |
| Johnson Creek | Natural | 15.8 | 10.8 | Fair | Fair |
| | Artificial | 12.2 | 13.7 | Fair | Poor |
| South Fork Salmon River | Natural | 21.2 | 12.4 | Fair | Poor |
| | Artificial | 7.2 | 15.3 | Fair | — |
| Elk Creek | Natural | 25.6 | 7.9 | Good | Good |
| | Artificial | 14.1 | 10.6 | Fair | Poor |

Table 33. — Accuracy, precision, and confidence intervals for streambank vegetative stability

| Stream | Streambank vegetative stability | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Units* | *± Percent* | | |
| Horton Creek | 3.3 | 2.2 | Excellent | Fair |
| Gance Creek | 1.8 | 5.7 | Good | Fair |
| Frenchman Creek | 3.3 | 2.5 | Excellent | Good |
| Johnson Creek | 3.3 | 2.4 | Excellent | Good |
| South Fork Salmon River | 3.5 | 2.3 | Excellent | Fair |
| Elk Creek | 2.8 | 3.5 | Excellent | Fair |

Table 34. — Accuracy, precision, and confidence intervals for streambank undercut

| Stream | Streambank undercut | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Feet* | *± Percent* | | |
| Horton Creek | 0.1 | 20.8 | Poor | Good |
| Gance Creek | .08 | 30.5 | Poor | Fair |
| Frenchman Creek | .5 | 15.2 | Fair | Poor |
| Johnson Creek | .3 | 16.1 | Fair | Poor |
| South Fork Salmon River | .4 | 14.2 | Fair | Good |
| Elk Creek | .5 | 13.9 | Fair | Good |

Table 35. — Accuracy, precision, and confidence intervals for streambank angle

| Stream | Channel bank angle | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Degrees* | *± Percent* | | |
| Horton Creek | 107.7 | 3.9 | Excellent | Good |
| Gance Creek | 118.5 | 3.7 | Excellent | Good |
| Frenchman Creek | 97.5 | 4.2 | Excellent | Good |
| Johnson Creek | 97.7 | 4.8 | Excellent | Poor |
| South Fork Salmon River | 103.9 | 6.6 | Good | Good |
| Elk Creek | 103.7 | 3.2 | Excellent | Good |

Table 36.—Accuracy, precision, and confidence intervals for streamside cover

| Stream | Streamside cover | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Units* | *± Percent* | | |
| Horton Creek | 2.3 | 3.2 | Excellent | Good |
| Gance Creek | 2.2 | 5.8 | Good | Poor |
| Frenchman Creek | 2.1 | 3.5 | Excellent | Poor |
| Johnson Creek | 2.4 | 3.4 | Excellent | Poor |
| South Fork Salmon River | 2.3 | 4.1 | Excellent | Poor |
| Elk Creek | 2.0 | 4.4 | Excellent | Poor |

## APPENDIX 3 (con.)

Table 37.—Accuracy, precision, and confidence intervals for vegetation use

| Stream | Vegetation use | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Percent* | *± Percent* | | |
| Horton Creek | 29.8 | 5.8 | Good | Excellent |
| Gance Creek | 44.9 | 8.5 | Good | Good |
| Frenchman Creek | 11.1 | 32.5 | Poor | Good |
| Johnson Creek | 25.5 | 9.2 | Good | Good |
| South Fork Salmon River | 8.6 | 1.5 | Excellent | Good |
| Elk Creek | 31.7 | 14.7 | Fair | Good |

Table 38. — Accuracy, precision, and confidence intervals for vegetation overhang

| Stream | Vegetation overhang | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Feet* | *± Percent* | | |
| Horton Creek | 0.5 | 8.3 | Good | Poor |
| Gance Creek | .1 | 33.1 | Poor | Poor |
| Frenchman Creek | .6 | 14.0 | Fair | Good |
| Johnson Creek | .6 | 13.4 | Fair | Poor |
| South Fork Salmon River | .8 | 13.5 | Fair | Good |
| Elk Creek | .5 | 12.0 | Fair | Good |

Table 39. — Accuracy, precision, and confidence intervals for habitat type

| Stream | Streamside habitat type | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Units* | *± Percent* | | |
| Horton Creek | 16.3 | 1.7 | Excellent | Good |
| Gance Creek | 9.4 | 6.9 | Good | Good |
| Frenchman Creek | 17.0 | 3.0 | Excellent | Good |
| Johnson Creek | 17.6 | 2.6 | Excellent | Fair |
| South Fork Salmon River | 14.9 | 3.3 | Excellent | Poor |
| Elk Creek | 13.5 | 4.2 | Excellent | Fair |

Table 40. — Accuracy, precision, and confidence intervals for fish environment

| Stream | Fish environment rating | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Units* | *± Percent* | | |
| Horton Creek | 2.6 | 3.6 | Excellent | Good |
| Gance Creek | 1.5 | 7.4 | Good | Poor |
| Frenchman Creek | 3.3 | 4.7 | Excellent | Good |
| Johnson Creek | 3.5 | 4.7 | Excellent | Good |
| South Fork Salmon River | 3.2 | 5.3 | Good | Poor |
| Elk Creek | 3.5 | 3.8 | Excellent | Poor |

Table 41. — Accuracy, precision, and confidence intervals for boulder

| Stream | Boulder | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Percent* | *± Percent* | | |
| Horton Creek | 0.0 | 0.0 | Excellent | Excellent |
| Gance Creek | 2.1 | 48.1 | Poor | Good |
| Frenchman Creek | 1.2 | 67.5 | Poor | Good |
| Johnson Creek | .0 | .0 | Excellent | Excellent |
| South Fork Salmon River | 1.5 | 30.1 | Poor | Excellent |
| Elk Creek | .1 | 99.4 | Poor | Good |

Table 42. — Accuracy, precision, and confidence intervals for rubble

| Stream | Rubble | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Percent* | *± Percent* | | |
| Horton Creek | 2.3 | 83.7 | Poor | Fair |
| Gance Creek | 9.3 | 29.5 | Poor | Fair |
| Frenchman Creek | 2.8 | 49.0 | Poor | Good |
| Johnson Creek | .0 | .0 | Excellent | Excellent |
| South Fork Salmon River | 8.8 | 25.1 | Poor | Good |
| Elk Creek | 8.1 | 27.9 | Poor | Poor |

Table 43. — Accuracy, precision, and confidence intervals for gravel

| Stream | Gravel | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Percent* | *± Percent* | | |
| Horton Creek | 74.1 | 6.4 | Good | Fair |
| Gance Creek | 73.8 | 5.4 | Good | Fair |
| Frenchman Creek | 58.9 | 7.8 | Good | Poor |
| Johnson Creek | 53.9 | 7.5 | Good | Poor |
| South Fork Salmon River | 47.1 | 7.1 | Good | Good |
| Elk Creek | 76.2 | 3.9 | Excellent | Poor |

Table 44. — Accuracy, precision, and confidence intervals for fine sediment

| Stream | | Percent fine sediment | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|---|
| | | | *± Percent* | | |
| Horton Creek | large | 8.6 | 51.9 | Poor | Fair |
| | fine | 16.5 | 29.1 | Poor | |
| Gance Creek | large | 4.3 | 43.5 | Poor | Fair |
| | fine | 9.0 | 28.3 | Poor | |
| Frenchman Creek | large | 25.4 | 15.6 | Fair | Poor |
| | fine | 26.0 | 14.0 | Fair | |
| Johnson Creek | large | 22.9 | 13.2 | Fair | Poor |
| | fine | 23.7 | 15.0 | Fair | |
| South Fork Salmon River | large | 21.2 | 12.0 | Fair | Good |
| | fine | 21.6 | 12.5 | Fair | |
| Elk Creek | large | 4.5 | 30.0 | Poor | Poor |
| | fine | 10.3 | 4.7 | Excellent | |

Table 45. — Accuracy, precision, and confidence intervals for embeddedness

| Stream | Embeddedness | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Units* | *± Percent* | | |
| Horton Creek | 3.5 | 4.3 | Excellent | Fair |
| Gance Creek | 3.3 | 4.6 | Excellent | Fair |
| Frenchman Creek | 2.6 | 6.4 | Good | Excellent |
| Johnson Creek | 2.7 | 5.4 | Good | Good |
| South Fork Salmon River | 2.6 | 7.7 | Good | Poor |
| Elk Creek | 3.5 | 3.7 | Excellent | Good |

Table 46. — Accuracy, precision, and confidence intervals for instream vegetative cover

| Stream | Instream vegetative cover | Confidence interval | Precision | Accuracy |
|---|---|---|---|---|
| | *Feet* | *± Percent* | | |
| Horton Creek | 0.6 | 24.2 | Poor | Fair |
| Gance Creek | .2 | 42.1 | Poor | Poor |
| Frenchman Creek | .7 | 31.4 | Poor | Good |
| Johnson Creek | .3 | 40.5 | Poor | Good |
| South Fork Salmon River | 6.5 | 8.1 | Good | Poor |
| Elk Creek | 5.5 | 11.0 | Fair | Good |

# APPENDIX 4

## Mathematical Proof of Needed Stream Depth Measurements

Given: A channel cross section underneath the transect, with water depths measured at one-fourth, one-half, and three-fourths the distance of the width of water. What is the average depth?

Cross section area = width × depth

so

$$\text{Average depth } (\overline{D}) = \frac{\text{Area (A)}}{\text{Width (W)}},$$

but the total area (A) and total width (W) are equal to the sum of the areas of the four parts of the cross section defined by the three depth measurements so

$$\overline{D} = \frac{A}{W} \frac{\sum_{i=1}^{4} \left(\frac{D_i + D_{i+1}}{2}\right)\left(\frac{W}{4}\right)}{W} = \sum_{i=1}^{4} \frac{D_i + D_i + 1}{8}$$

$$\overline{D} = \frac{D_1 + D_2 + D_2 + D_3 + D_3 + D_4 + D_4 + D_5}{8}$$

$$\overline{D} = \frac{D_1 + 2D_2 + 2D_3 + 2D_4 + D_5}{8},$$

but $D_1$ and $D_5 = 0$; therefore

$$\overline{D} = \frac{2D_2 + 2D_3 + 2D_4}{8} = \frac{D_2 + D_3 + D_4}{4}.$$

# APPENDIX 5

## Stream Habitat and Fishery Rating Variables that Failed to Show Promise

### BANK-TO-BANK WIDTH

The bank-to-bank width is the distance from the top of the right streambank along the transect line to the top of the left streambank. The top of the bank is usually at that point where the verti cal slope of the bank sloping away from the water column changes to a horizontal slope. This measurement was recorded to the nearest foot (0.31 m), but for more accuracy it should be recorded in tenths of feet (0.03 m). After 3 years of measuring this attribute, we concluded we could not measure bank-to-bank width with precision with this approach because of the inability of the observers to accurately select the two points representing the top of the banks.

Confidence intervals around the means were extremely large and year-to-year precision and accuracy in the measurements rated very low. If this measurement is needed, it should be done in combination with the cross section profile, which allows the points to be permanently set or accurately determined.

### HIGH WATER STREAM WIDTH

This measurement is taken as the measurement for existing water stream width, except that the high water measurement begins at the high water mark on one bank and ends at the high water mark on the opposite bank. This measurement was recorded to the nearest foot (0.31 m), but should be measured to a tenth of a foot (0.03 m). After 3 years of testing we concluded this measurement could not be taken accurately using this method. High water marks were constantly changing, were hard to define, and on some stream reaches within broad flat flood plains where the stream averaged 30 ft (9.1 m) in width during low flows, the high water stream width could average over 1,200 ft (366 m) or more. If this measurement is needed, it should be obtained by onsite checks during the high flow period to correctly mark the high water points on both banks.

### SUN ANGLE

The angle made by the arc of the sun as it intercepts the midpoint of the transect is measured with a clinometer. The angle of the arc is easily determined by the day of the year. For uniformity, we used the sun's arc on August 1 for all measurements taken during the season.

The sum of the two clinometer readings that measure the angle on each side of the stream from the channel horizontal to the sun horizon are subtracted from 180 to obtain the sun arc degrees (fig. 27). Examples of conditions intercepting the rays and reducing the degrees of the arc are streamside vegetation, logs, debris, bridges, trees, high streambanks, and narrow canyons. We found this measurement correlated well with fish standing crop in our higher elevation streams with increasing sun arc resulting in increasing fish standing crop. The measurement had good year-to-year accuracy and precision rating and had narrow confidence intervals. Even with these merits, which are hard to find in most attributes, we are still not sure how to handle these data after they are collected.

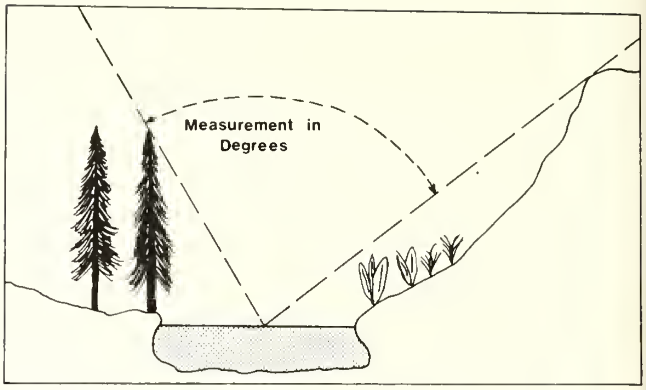


**Figure 27. — Measurement of sun arc degrees.**

### STREAMBANK ROCK CONTENT

Streambanks intercepted by the transect line are evaluated for percent rock content. We found it difficult to rate rock content because streambank cover makes it impossible to determine the true composition of the bank. Only by digging soil pits could we get an accurate estimate because the streambank materials usually are lensed and change drastically in composition from one spot to another. We finally dropped this rating because of the difficulty in getting reliable data without digging pits. The rock content of the exposed channel is available from the substrate analysis and would be more meaningful. Streambank rock content is rated as shown:

| Rating | Description |
|---|---|
| 5 | Over 95 percent of the bank material is more than 0.19 inch (4.7 mm) in particle size. The majority of the material is boulder or rubble. |
| 4 | From 75 to 94 percent of the bank material is more than 0.19 inch in particle size. The majority of the material is boulder or rubble, but if the majority is gravel, the rate is 3. |
| 3 | From 50 to 74 percent of the bank material is more than 0.19 inch in particle size. The majority of the material is boulder or rubble, but if the majority is gravel, the rate is 2. |
| 2 | From 25 to 49 percent of the bank material is over 0.19 inch in particle size diameter, but if the majority of the material is gravel, the rate is 1. |
| 1 | Less than 25 percent of the bank material is over 0.19 inch, but if the majority of the material is rubble and boulder, the rate is 2. |

### FISH STREAMSIDE ENVIRONMENT

This evaluation includes cover mainly as it relates to catchable size fish (table 47). Young-of-the-year and other age groups of small fish are not adequately considered in this evaluation.

**Table 47. —** Fish streamside environment rating

| Description | | Go to block | Rating |
|---|---|---|---|
| 1a | Contact zone is pool | 2 | |
| 1b | Contact zone is riffle | 5 | |
| 2a | Contact zone pool rates 5 | 3 | |
| 2b | Contact zone pool rates 3 or 4 | 4 | |
| 2c | Contact zone pool rates 1 or 2 | 5 | |
| 3a | Cover is abundant | | 5 |
| 3b | Cover is intermediate | | 4 |
| 3c | Cover is lacking | | 3 |
| 4a | Cover is abundant | | 4 |
| 4b | Cover is intermediate | | 3 |
| 4c | Cover is lacking | | 2 |
| 5a | Cover is abundant | | 3 |
| 5b | Cover is intermediate | | 2 |
| 5c | Cover is lacking | | 1 |

The area to be evaluated is the border between the streambank or channel and the shoreline water columns. Only that area intercepted by the transect line is evaluated, although areas outside of this are considered to obtain the pool quality and cover ratings. High rating values would be considered to indicate better conditions for catchable salmonids. We have not evaluated this rating to see if it is of any value in predicting fish populations.

## CHANNEL STABILITY

Stream channel stability rates the channel as to whether it is stable, aggrading, or eroding. It is an estimate of the rate the channel moves horizontally or vertically. Stream channel stability is rated as shown:

| Rating | Description |
|---|---|
| 3 | Stable |
| 2 | Aggrading |
| 1 | Eroding |

The rating is based on subjective judgment, so after 2 years of use, observer error, and inability to determine if the channel had scoured or filled, we discarded it. The cross-section profile measurements can indicate channel stability, but will not determine if the channel is aggrading or degrading. The chain method does determine this.

## APPENDIX 6

FPSP-AI: A BASIC Computer Program Designed for the Hewlett-Packard HP9845 that Calculates Population Estimates Using a Removal-Depletion Maximum-Likelihood Formula.

```
160   !       CALCULATIONS MADE      CORRESPONDING VARIABLE NAMES
170   !
180   !  1.   Population estimate                  1. Popest
190   !  2.   Population estimate variance         2. Popsizvar
200   !  3.   Pop. est. standard error             3. Sepopsiz
210   !  4.   Pop. est. upper conf. interval       4. Upconfintpop
220   !  5.   Pop. est. lower conf. interval       5. Loconfintpop
230   !
240   !  6.   Capture probability estimate         6. Captprob = Phat
250   !  7.   Capt. prob. estimate variance        7. Varcaptprob
260   !  8.   Capt. prob. est. std. error          8. Secaptprob
270   !  9.   Capt. prob. est. up. conf. int.      9. Upconfintcapt
280   ! 10.   Capt. prob. est. lo. conf. int.     10. Loconfintcapt
290   !
300   ! 11.   Chi square goodness-of-fit          11.  Chisquare
310   !
320   !...............................................................
330   !  SECTION 1:  INPUT INFORMATION.
340   !  Asks the user to input the number of removals
350   !  [Numofrmvls] made and the number of fish caught per
360   !  removal [Numfishprrmvl(Rmvl)].  Total catch [S] and
370   !  a function [C] are calculated for use in the
380   !  population estimate computation.
390   !
400   DIM Expnumfish(4),Numfishprrmvl(4)
410   INPUT "ENTER THE NAME OF THE STREAM",Stream$
420   PRINT Stream$
430   INPUT "ENTER THE NAME OF THE SPECIES",Species$
440   PRINT Species$
450   INPUT "HOW MANY REMOVALS?",Numofrmvls
460   PRINT Numofrmvls
470   T=Numofrmvls
480   FOR Rmvl=1 TO Numofrmvls
490     PRINT "HOW MANY FISH CAUGHT IN REMOVAL";Rmvl;"?"
500     INPUT Numfishprrmvl(Rmvl)
510     PRINT Numfishprrmvl(Rmvl)
```

```
520      S=S+Numfishprrmvl(Rmvl)
530      C=C+Numfishprrmvl(Rmvl)*Rmvl
540    NEXT Rmvl
550    !
560    !.............................................................
570    !   SECTION 2:  SEARCH FOR POP.EST. OF HIGHEST PROBABILITY.
580    !   Population estimates are calculated for S+0, S+1, S+2,
590    !   etc., until the population function [Theta] reaches a
600    !   maximum point.  This point corresponds to the
610    !   population estimate of maximum liklihood.  The variable
620    !   [I] is used to increment [S] by one each time through
630    !   the loop.  A summation term [Firstterm] is defined as
640    !   zero when [I]=0.
650    !
660    Firstterm=I=Theta=Oldtheta=0        ! Initialize variables.
670    Phat=S/C
680    GOTO 760    ! Calculation of summation term (Firstterm) is
690                ! skipped when I=0 to prevent division by zero.
700                ! Firstterm is set initially to zero.
710    I=I+1
720    Phat=S/(C+T*I)
730    Firstterm=Firstterm+LOG(1+S/I)     ! LOG(X) takes the
740                                       ! natural log of X.
750    Oldtheta=Theta
760    Theta=Firstterm+S*LOG(Phat)+(C-S+T*I)*LOG(1-Phat)
770    IF (Oldtheta<Theta) OR (I=0) THEN 710  !Looks for Theta
780                                           !to reach a max.
790    !
800    !.............................................................
810    !   SECTION 3:  POPULATION ESTIMATE STATISTICS.
820    !   This section is entered when [Theta] reaches a maximum
830    !   point (i.e. the loop in SECTION 2 has been exited).
840    !   The statistics corresponding to the maximum liklihood
850    !   estimate are calculated.
860    !
870    Popest=I-1+S
880    Captprob=Phat=S/(C+T*(I-1))
890
Popsizvar=Popest*(1-Phat)**T*(1-(1-Phat)**T)/((1-(1-Phat)**T)**2
-(T*Phat)**2*(1-Phat)**(T-1))
900    Sepopsiz=SQR(Popsizvar)
910    Tvalue=1.96     ! The T-value is assumed to be 1.96
920    Confintpop=Tvalue*Sepopsiz
930    Upconfintpop=Popest+Confintpop
940    Loconfintpop=Popest-Confintpop
950    IF Loconfintpop<S THEN Loconfintpop=S
960    !
970    !.............................................................
980    !   SECTION 4:  CAPTURE PROBABILITY STATISTICS.
990    !   The capture probability statistics corresponding to the
1000   !   maximum liklihood estimate are calculated.
1010   !
```

```
1020  Varcaptprob=(Captprob/Popest)**2*(Popsizvar/(1-Captprob)**
(T-1))
1030  Secaptprob=SQR(Varcaptprob)
1040  Confintcapt=Tvalue*Secaptprob
1050  Upconfintcapt=Captprob+Confintcapt
1060  Loconfintcapt=Captprob-Confintcapt
1070  IF Loconfintcapt<0 THEN Loconfintcapt=0
1080  !
1090  !.........................................................
1100  !  SECTION 5:  CHI SQUARE CALCULATION.
1110  !  The expected number of fish caught is calculated for
1120  !  each removal [Expnumfish(Rmvl)] and for the total catch
1130  !  [Exptotnumfish].  These numbers are compared with the
1140  !  actual number of fish caught to yield the chi square
1150  !  [Chisquare] statistic.
1160  !
1170  Exptotnumfish=Totnumfishcot=Chisqsumterm=0
1180  FOR Rmvl=1 TO Numofrmvls
1190    Expnumfish(Rmvl)=Popest*(1-Captprob)**(Rmvl-1)*Captprob
1200    Chisqsumterm=Chisqsumterm+(Numfishprrmvl(Rmvl)-Expnumfis
h(Rmvl))**2/Expnumfish(Rmvl)
1210    Exptotnumfish=Exptotnumfish+Expnumfish(Rmvl)
1220    Totnumfishcot=Totnumfishcot+Numfishprrmvl(Rmvl)
1230  NEXT Rmvl
1240  Chisquare=Chisqsumterm+(Totnumfishcot-Exptotnumfish)**2/Ex
ptotnumfish
1250  !
1260  !.........................................................
1270  !  SECTION 6:  OUTPUT.
1280  !  The information calculated above is printed.  PRINT
1290  !  USING and IMAGE statements allow formatting where
1300  !
1310  !  X is a blank space,
1320  !  K is a string constant,
1330  !  A is a string character (strings are left-justified
1340  !       with blanks filling out the rest of the field),
1350  !  D is a digit position,
1360  !  Z is also a digit position (leading zeros are replaced
1370  !       with 0 as a fill character).
1380  !
1390  !  Prefix numbers refer to the number of occurrences.  For
1400  !  example, 7X specifies seven blank spaces.
1410  !
1420  PRINTER IS 0   ! This statement activates the printer.
1430  PRINT USING "K,31A,K,25A";"STREAM:  ",Stream$,"SPECIES:  "
,Species$
1440  PRINT
1450  PRINT USING "K,7X,K,5D";"TOTAL CATCH","=",S
1460  IMAGE K,4X,K,5D,16X,K,6X,K,Z.5D
1470  PRINT USING 1460;"POPULATION EST","=",Popest,"CAPTURE PROB
","= ",Captprob
1480  IMAGE K,3X,K,DZ.3D,14X,K,Z.5D
```

```
1490  PRINT USING 1480;"POP EST STD ERR","= ",Sepopsiz,"CAPT PRO
B STD ERR = ",Secaptprob
1500  IMAGE K,4DZ.2D,12X,K,Z.5D
1510  PRINT USING 1500;"LOWER CONF INTRVL = ",Loconfintpop,"LOWE
R CONF INTRVL = ",Loconfintcapt
1520  PRINT USING 1500;"UPPER CONF INTRVL = ",Upconfintpop,"UPPE
R CONF INTRVL = ",Upconfintcapt
1530  PRINT
1540  IMAGE K,8X,K,DZ.4D,13X,K,4(4D,X)
1550  PRINT USING 1540;"CHI SQUARE","= ",Chisquare,"REMOVAL PATT
ERN:  ",Numfishprrmvl(1),Numfishprrmvl(2),Numfishprrmvl(3),Numfi
shprrmvl(4)
1560  PRINTER IS 16     ! Printer is turned off.
1570  END
```

---

EXAMPLE OF <u>FPSP-AI</u> OUTPUT.

```
STREAM:  So. Fk. Salmon R.        SPECIES:  Rainbow Trout

TOTAL CATCH          =  111
POPULATION EST       =  116       CAPTURE PROB          = 0.53110
POP EST STD ERR      =  3.481     CAPT PROB STD ERR     = 0.04964
LOWER CONF INTRVL    =    111.00  LOWER CONF INTRVL     = 0.43381
UPPER CONF INTRVL    =    122.82  UPPER CONF INTRVL     = 0.62839

CHI SQUARE           =   0.2638   REMOVAL PATTERN:  60   30   15   6
```

---

EXAMPLE OF <u>FPSP-AI</u> INTERNAL CALCULATIONS.

| I | SUMM. TERM | CAPTURE PROB | THETA |
|---|---|---|---|
| 0 | 0.0 | 0.587301587302 | -128.109045019 |
| 1 | 4.71849887128 | 0.575129533679 | -126.871876966 |
| 2 | 8.75273950942 | 0.563451776650 | -126.206675228 |
| 3 | 12.3903256691 | 0.552238805970 | -125.833238175 |
| 4 | 15.7489634363 | 0.541463414634 | -125.640520400 |
| 5 | 18.8931157150 | 0.531100478469 | -125.570077691 |
| 6 | 21.8635301806 | 0.521126760563 | -125.586621814 |

Note that Theta is maximized when I=5. The population estimate (116) equals the total catch (111) plus I (5).

# APPENDIX 7

## Tolerance Quotients of Aquatic Macroinvertebrates (from Winget and Mangum 1979)

**Table 48.** — Tolerance quotients (TQ) of aquatic macroinvertebrates based upon tolerance to alkalinity, sulfate, and sedimentation including low stream gradients

| Taxa | TQ |
|---|---|
| Phylum Coelenterata | 108 |
| Class Hydrozoa | 108 |
| Phylum Aschelminthes | 108 |
| Class Nematoda | 108 |
| Phylum Mollusca | 108 |
| Class Gastropoda | 108 |
| Family Lymnaidae | 108 |
| *Lymnaea* | 108 |
| Family Physidae | 108 |
| *Physa* | 108 |
| Family Planorbidae | 108 |
| Phylum Annelida | 108 |
| Class Hirudinea | 108 |
| Class Oligochaeta | 108 |
| Family Tubificidae | 108 |
| *Tubifex* | 108 |
| Family Lumbricidae | 108 |
| *Lumbricus aquaticus* | 108 |
| Phylum Platyhelminthes | |
| Class Turbellaria | 108 |
| Order Tricladida | 108 |
| Phylum Arthropoda | |
| Class Arachnida | |
| Suborder Hydracarina | 108 |
| Class Crustacea | 108 |
| Order Isopoda | 108 |
| Family Asellidae | 108 |
| *Asellus* | 108 |
| Order Amphipoda | 108 |
| Family Talitridae | 108 |
| *Hyalella azteca* | 108 |
| Family Gammaridae | 108 |
| *Gammarus lacustris* | 108 |
| Order Decapoda | 108 |
| Family Astacida | 108 |
| *Pacifastacus gambeli* | 108 |
| *Cambarus laevis* | 108 |
| Order Cladocera | 108 |
| *Daphnia* | 108 |
| Order Copepoda | 108 |
| Order Ostracoda | 108 |
| Class Insecta | 108 |
| Order Collembola | 108 |
| Family Poduridae | 108 |
| *Podura aquatica* | 108 |
| Family Entomobryidae | 108 |
| Order Megaloptera | 72 |
| Family Sialidae | 72 |
| *Sialis* | 72 |
| Family Corydalidae | 72 |
| *Corydalus cognata* | 72 |
| Order Lepidoptera | 72 |
| Family Pyralidae | 72 |
| *Parargyractis kearfottalis* | 72 |
| Order Ephemeroptera | 72 |
| Family Siphlonuridae | 72 |
| *Ameletus* | 48 |
| *Siphlonurus occidentalis* | 72 |
| *Isonychia* | 48 |
| Family Baetidae | 72 |
| *Baetis* spp. | 72 |
| *Callibaetis* | 72 |
| *Pseudocloeon* | 72 |
| *Centroptilum* | 36 |
| *Dactylobaetis* | 36 |
| *Paracloeodes* | 72 |
| Family Oligoneuriidae | 36 |
| *Lachlania saskatchewanensis* | 36 |
| *Homeoneuria* | 36 |
| Family Heptageniidae | 48 |
| *Heptagenia* | 48 |
| *Stenonema* | 48 |
| *Cinygmula* | 21 |
| *Rhithrogena* | 21 |
| *Epeorus* | 21 |
| *Anepeorus* | 48 |
| Family Leptophlebiidae | 36 |
| *Paraleptophlebia* | 24 |
| *Leptophlebia* | 24 |
| *Choroterpes* | 36 |
| *Traverella* | 36 |
| Family Tricorythidae | 108 |
| *Tricorythodes* | 108 |
| *Leptohyphes* | 72 |
| Family Ephemerellidae | 48 |
| *Ephemerella* | 48 |
| *Ephemerella grandis* | 24 |
| *Ephemerella doddsi* | 4 |
| *Ephemerella coloradensis* | 18 |
| *Ephemerella tibialis* | 24 |
| *Ephemerella inermis* | 48 |
| *Ephemerella infrequens* | 48 |
| *Ephemerella spinifera* | 24 |
| Family Ephemeridae | 36 |
| *Ephemera simulans* | 36 |
| *Hexagenia limbata* | 36 |
| Family Caenidae | 72 |
| *Caenis* | 72 |
| *Brachycerus* | 72 |
| Family Polymitarcidae | 48 |
| *Ephoron* | 48 |
| Order Odonata | |
| Family Cordulegastridae | 72 |
| *Cordulegaster* | 72 |
| Family Gomphidae | 108 |
| *Gomphus* | 108 |
| *Erpetogomphus compositus* | 72 |
| *Ophiogomphus severus* | 108 |
| *Progomphus borealis* | 72 |
| Family Aeshnidae | 72 |
| *Aeshna* | 72 |
| *Anax* | 72 |
| *Oplonaeschna* | 72 |
| Family Libellulidae | 72 |
| *Cordulia shurtleffi* | 72 |
| *Erythemis* | 72 |
| *Leucorrhinia* | 72 |
| *Libellula* | 72 |
| *Sympetrum* | 72 |
| *Somatochlora* | 72 |
| Family Agrionidae | 108 |
| *Hetaerina americana* | 108 |
| *Calopteryx* | 108 |

| Taxa | TQ |
|---|---|
| Family Lestidae | 108 |
| *Archilestes* | 108 |
| *Lestes* | 108 |
| Family Coenagrionidae | 108 |
| *Argia* | 108 |
| *Amphiagrion* | 72 |
| *Enallagma* | 72 |
| *Ischnura* | 72 |
| *Coenagrion* | 72 |
| *Telebasis salva* | 72 |
| Order Hemiptera | |
| Family Belastomatidae | 72 |
| *Belastoma* | 72 |
| *Benacus* | 72 |
| *Lethocerus* | 72 |
| *Abedus* | 72 |
| Family Corixidae | 108 |
| *Callicorixa* | 108 |
| *Hesperocorixa* | 108 |
| *Corisella* | 108 |
| *Trichocorixa* | 108 |
| *Cenocorixa* | 108 |
| *Graptocorixa* | 108 |
| *Arctocorixa* | 108 |
| *Sigara* | 108 |
| Family Gerridae | 72 |
| *Gerris* | 72 |
| *Rheumatobates* | 72 |
| Family Naucoridae | 72 |
| *Ambrysus mormon* | 72 |
| *Pelocoris* | 72 |
| Family Notonectidae | 108 |
| *Notonecta* | 108 |
| *Buenoa* | 108 |
| Family Veliidae | 72 |
| *Microvelia americana* | 72 |
| *Rhagovelia distincta* | 72 |
| Family Mesoveliidae | 72 |
| *Mesovelia* | 72 |
| Family Macroveliidae | 72 |
| *Macrovelia* | 72 |
| Order Plecoptera | |
| Family Nemouridae | 36 |
| *Amphinemura* | 6 |
| *Malenka* | 36 |
| *Prostoia besametsa* | 24 |
| *Podmosta* | 12 |
| *Zapada* | 16 |
| *Nemoura* | 24 |
| Family Capniidae | 32 |
| *Capnia* | 32 |
| *Eucapnopsis* | 18 |
| *Isocapnia* | 24 |
| *Mesocapnia frisoni* | 32 |
| *Utacapnia* | 18 |
| Family Taeniopterygidae | 48 |
| *Taenionema* | 48 |
| *Doddsia* | 24 |
| *Oemopteryx* | 48 |
| Family Leuctridae | 18 |
| *Paraleuctra* | 18 |
| *Perlomymia* | 18 |
| Family Pteronarcyidae | 24 |
| *Pteronarcella badia* | 24 |
| *Pteronarcys californica* | 18 |
| *Pteronarcys princeps* | 24 |
| Family Perlodidae | 48 |
| *Megarcys signata* | 24 |
| *Skwala parallela* | 18 |

| Taxa | TQ |
|---|---|
| *Cultus aestivalis* | 12 |
| *Isogenoides* | 24 |
| *I. elongatus* | 24 |
| *I. zionensis* | 24 |
| *Kogotus modestus* | 18 |
| *Pictetiella expansa* | 18 |
| *Diura knowltoni* | 24 |
| *Isoperla* | 48 |
| *I. ebria* | 24 |
| *I. fulva* | 48 |
| *I. mormona* | 48 |
| *I. quinquepunctata* | 48 |
| Family Chloroperlidae | 24 |
| Family Perlidae | 24 |
| *Acroneuria abnormis* | 6 |
| *Claassenia sabulosa* | 6 |
| *Hesperoperla pacifica* | 18 |
| *Perlesta placida* | 24 |
| *Doronuria theodora* | 18 |
| Order Trichoptera | |
| Family Rhyacophilidae | 18 |
| *Rhyacophila* | 18 |
| *Atopsyche* | 18 |
| *Himalopsyche* | 18 |
| Family Glossosomatidae | 32 |
| *Glossosoma* | 24 |
| *Anagapetus* | 24 |
| *Protoptila* | 32 |
| *Culoptila* | 32 |
| Family Philopotamidae | 24 |
| *Chimarra* | 24 |
| *Doliphilodes (sortosa)* | 24 |
| *Wormaldia* | 24 |
| Family Psychomyidae | 108 |
| *Polycentropus* | 108 |
| *Nyctiophylax* | 108 |
| *Psychomyia* | 108 |
| *Tinodes* | 108 |
| Family Hydropsychidae | 108 |
| *Hydropsyche* | 108 |
| *Cheumatopsyche* | 108 |
| *Arctopsyche* | 18 |
| *Smicridea* | 72 |
| *Diplectrona* | 48 |
| *Macronema* | 48 |
| *Parapsyche* | 6 |
| Family Hydroptilidae | 108 |
| *Hydroptila* | 108 |
| *Agraylea* | 108 |
| *Ochrotrichia* | 108 |
| *Neotrichia* | 108 |
| *Ithytrichia* | 108 |
| *Oxyethira* | 108 |
| *Leucotrichia* | 108 |
| *Alisotrichia* | 108 |
| *Mayatrichia* | 108 |
| Family Limnephilidae | 108 |
| *Limnephilus* | 108 |
| *Dicosmoecus* | 24 |
| *Hesperophylax* | 108 |
| *Oligophlebodes* | 24 |
| *Apatania* | 18 |
| *Amphicosmoecus* | 18 |
| *Neothremma* | 8 |
| *Lenarchus* | 18 |
| *Chyranda* | 18 |
| *Psychoglypha* | 24 |
| *Ecclisomyia* | 24 |
| *Homophylax* | 18 |

| Taxa | TQ |
| --- | --- |
| *Allocosmoecus* | 18 |
| *Asynarchus* | 108 |
| *Clistorania* | 108 |
| *Grammotaulius* | 108 |
| *Imania* | 48 |
| *Neophylax* | 24 |
| *Onocosmoecus* | 18 |
| *Pycnopsyche* | 72 |
| Family Leptoceridae | 54 |
| *Oecetis* | 54 |
| *Leptocella* | 54 |
| *Triaenodes* | 54 |
| *Mystacides* | 54 |
| *Ceraclea* | 54 |
| Family Lepidostomatidae | 18 |
| *Lepidostoma* | 18 |
| Family Brachycentridae | 24 |
| *Brachycentrus* | 24 |
| *Micrasema* | 24 |
| *Oligoplectrum* | 24 |
| *Amiocentrus* | 24 |
| Family Helicopsychidae | 18 |
| *Helicopsyche borealis* | 18 |
| Family Polycentropodidae | 72 |
| *Polycentropus* | 72 |
| *Nictiophylax* | 72 |
| Family Sericostomatidae | 72 |
| *Gumaga* | 72 |
| Order Coleoptera | |
| Family Haliplidae | 54 |
| *Brychius* | 54 |
| *Haliplus* | 54 |
| *Peltodytes* | 54 |
| Family Dytiscidae | 72 |
| *Derovatellus* | 72 |
| *Laccophilus* | 72 |
| *Bidessus* | 72 |
| *Agabus* | 72 |
| *Hygrotus* | 72 |
| *Hydroporous* | 72 |
| *Oreodytes* | 72 |
| *Hybius* | 72 |
| *Rhanius* | 72 |
| *Dytiscus* | 72 |
| *Acilius* | 72 |
| *Cybister* | 72 |
| *Deronectes* | 72 |
| *Thermonectus* | 72 |
| *Coptotomus* | 72 |
| Family Hydrophilidae | 72 |
| *Helophorous* | 72 |
| *Hydrochara* | 72 |
| *Berosus* | 72 |
| *Enochrus* | 72 |
| *Hydrophilus* | 72 |
| *Tropisternus* | 72 |
| *Hydrobius* | 72 |
| *Paracymus* | 72 |
| *Crenitis* | 72 |
| *Ametor* | 72 |
| *Helochares* | 72 |
| *Laccobius* | 72 |
| *Enochrous* | 72 |
| *Cymbiodyta* | 72 |
| Family Elmidae | 108 |
| *Zaitzevia* | |
| *Narpus* | |
| *Stenelmis* | |
| *Dubiraphia* | |

| Taxa | TQ |
| --- | --- |
| *Optioservus* | 108 |
| *Heterlimnius* | |
| *Elmis* | |
| *Simsonia* | |
| *Microcylloepus* | |
| *Lara* | |
| Family Cyrinidae | 108 |
| *Gyrinus* | 108 |
| Family Amphizoidae | 24 |
| *Amphizoa* | 24 |
| Family Hydraenidae | 72 |
| Order Diptera | |
| Family Tipulidae | 72 |
| *Antocha monticola* | 24 |
| *Dicranota* | 24 |
| *Hexatoma* | 36 |
| *Holorusia grandis* | 72 |
| *Helobia* | 36 |
| *Tipula* | 36 |
| Family Psychodidae | 36 |
| *Maruina* | 36 |
| *Psychoda* | 36 |
| *Pericoma* | 36 |
| Family Blephariceridae | 2 |
| *Bibiocephala grandis* | 2 |
| *Agathon* | 2 |
| Family Deuterophlebiidae | 4 |
| *Deuterophlebia coloradensis* | 4 |
| Family Culicidae | 108 |
| *Aedes* | 108 |
| *Culex* | 108 |
| *Anopheles* | 108 |
| *Mansonia* | 108 |
| *Psorophora* | 108 |
| *Culiseta* | 108 |
| Family Dixidae | 108 |
| *Dixa* | 108 |
| Family Simuliidae | 108 |
| Family Chironomidae | 108 |
| Family Ceratopogonidae | 108 |
| Family Stratiomyidae | 108 |
| *Euparyphus* | 108 |
| Family Tabanidae | 108 |
| *Tabanus* | 108 |
| Family Rhagionidae | 24 |
| *Atherix pachypus* | 24 |
| Family Dolichopodidae | 108 |
| Family Empididae | 108 |
| *Hermerodromia* | 108 |
| Family Ephydridae | 108 |
| *Ephydra* | 108 |
| Family Muscidae | 108 |
| *Limnophora* | 108 |
| Family Syrphidae | 108 |
| *Chrysogastera* | 108 |
| *Tubifera* | 108 |
| *Helophilus* | 108 |

## APPENDIX 8

# A Key to Community Tolerance Quotients (from Winget and Mangum 1979)

**Table 49.**—A key giving Predicted Community Tolerance Quotients (CTQp) for various combinations of gradient (percent), substrates, total alkalinity as milligrams per liter calcium carbonate, and sulfate as milligrams per liter sulfate for any given stream

| | Go to key number | CTQp |
|---|---|---|
| 1. Stream gradient 0.1-1.2 | 2 | |
| 1.3-3.0 | 15 | |
| 3.0 | 28 | |
| 2. Substrate mostly boulder and rubble | 3 | |
| Gravel and rubble | 7 | |
| Sand and boulder, Rubble or gravel | 11 | |
| 3. Total alkalinity 0-199 | 4 | |
| 200-300 | 5 | |
| >300 | 6 | |
| 4. Sulfate 0-149 | | 51 |
| 150-300 | | 71 |
| >300 | | 90 |
| 5. Sulfate 0-149 | | 53 |
| 150-300 | | 71 |
| >300 | | 90 |
| 6. Sulfate 0-149 | | 90 |
| 150-300 | | 96 |
| >300 | | 108 |
| 7. Total alkalinity 0-199 | 8 | |
| 200-300 | 9 | |
| >300 | 10 | |
| 8. Sulfate 0-149 | | 53 |
| 150-300 | | 85 |
| >300 | | 103 |
| 9. Sulfate 0-149 | | 55 |
| 150-300 | | 86 |
| >300 | | 103 |
| 10. Sulfate 0-149 | | 89 |
| 150-300 | | 97 |
| >300 | | 108 |
| 11. Total alkalinity 0-199 | 12 | |
| 200-300 | 13 | |
| >300 | 14 | |
| 12. Sulfate 0-149 | | 60 |
| 150-300 | | 90 |
| >300 | | 108 |
| 13. Sulfate 0-149 | | 60 |
| 150-300 | | 90 |
| >300 | | 108 |
| 14. Sulfate 0-149 | | 90 |
| 150-300 | | 99 |
| >300 | | 108 |
| 15. Substrate mostly boulder and rubble | 16 | |
| Gravel and rubble | 20 | |
| Sand and boulder, rubble or gravel | 24 | |
| 16. Total alkalinity 0-199 | 17 | |
| 200-300 | 18 | |
| >300 | 19 | |

| | Go to key number | CTQp |
|---|---|---|
| 17. Sulfate 0-149 | | 50 |
| 150-300 | | 65 |
| >300 | | 90 |
| 18. Sulfate 0-149 | | 50 |
| 150-300 | | 65 |
| >300 | | 90 |
| 19. Sulfate 0-149 | | 90 |
| 150-300 | | 96 |
| >300 | | 108 |
| 20. Total alkalinity 0-199 | 21 | |
| 200-300 | 22 | |
| >300 | 108 | |
| 21. Sulfate 0-149 | | 50 |
| 150-300 | | 80 |
| >300 | | 103 |
| 22. Sulfate 0-149 | | 55 |
| 150-300 | | 80 |
| >300 | | 108 |
| 23. Sulfate 0-149 | | 80 |
| 150-300 | | 96 |
| >300 | | 108 |
| 24. Total alkalinity 0-199 | 25 | |
| 200-300 | 26 | |
| >300 | 27 | |
| 25. Sulfate 0-149 | | 66 |
| 150-300 | | 88 |
| >300 | | 108 |
| 26. Sulfate 0-149 | | 65 |
| 150-300 | | 88 |
| >300 | | 108 |
| 27. Sulfate 0-149 | | 85 |
| 150-300 | | 93 |
| >300 | | 108 |
| 28. Substrate mostly boulder and rubble | 29 | |
| Gravel and rubble | 33 | |
| Sand and boulder, rubble or gravel | 37 | |
| 29. Total alkalinity 0-199 | 30 | |
| 200-300 | 31 | |
| >300 | 32 | |
| 30. Sulfate 0-149 | | 50 |
| 150-300 | | 62 |
| >300 | | 100 |
| 31. Sulfate 0-149 | | 50 |
| 150-300 | | 62 |
| >300 | | 108 |
| 32. Sulfate 0-149 | | 85 |
| 150-300 | | 90 |
| >300 | | 108 |
| 33. Total alkalinity 0-199 | 34 | |
| 200-300 | 35 | |
| >300 | 36 | |
| 34. Sulfate 0-149 | | 50 |
| 150-300 | | 77 |
| >300 | | 108 |
| 35. Sulfate 0-149 | | 50 |
| 150-300 | | 77 |
| >300 | | 108 |

**APPENDIX 8** (con.)

| | Go to key number | CTQp |
|---|---|---|
| 36. Sulfate 0-149 | | 90 |
| 150-300 | | 99 |
| >300 | | 108 |
| 37. Total alkalinity 0-199 | 38 | |
| 200-300 | 39 | |
| >300 | 40 | |
| 38. Sulfate 0-149 | | 80 |
| 150-300 | | 100 |
| >300 | | 108 |
| 39. Sulfate 0-149 | | 80 |
| 150-300 | | 100 |
| >300 | | 108 |
| 40. Sulfate 0-149 | | 100 |
| 150-300 | | 108 |
| >300 | | 108 |

# APPENDIX 9

## Biotic Index for Chandler's Score

**Table 50.** — Biotic index for Chandler's score as adapted by Cook (1976) for an eastern North American stream

| Groups present in sample | Increasing abundance: Present | Few | Common | Abundant | Very abundant |
|---|---|---|---|---|---|
| | *Points scored* | | | | |
| Each species of Perlidae, Perlodidae, Chloroperlidae, Taeniopteryginae | 90 | 94 | 98 | 99 | 100 |
| Each species of Nemouridae (excluding Taeniopteryginae), Astacidae | 84 | 89 | 94 | 97 | 98 |
| Each species of Ephemeroptera (excluding *Baetis*) | 79 | 84 | 90 | 94 | 97 |
| Each species of cased caddis, Megaloptera, *Agrion* (Zygoptera) | 75 | 80 | 86 | 91 | 94 |
| Each species of *Ancylus* | 70 | 75 | 82 | 87 | 91 |
| *Rhyacophila* (Trichoptera) | 65 | 70 | 77 | 83 | 88 |
| Genera of *Dicranota, Limnophora,* Tipulidae | 60 | 65 | 72 | 78 | 84 |
| Genera of *Simulium, Pristina* | 56 | 61 | 67 | 73 | 75 |
| Genera of Coleoptera (excluding *Stenelmis*), Nematoda | 51 | 55 | 61 | 66 | 72 |
| — Ceratopongidae | 47 | 50 | 54 | 58 | 63 |
| — *Baetis* (Ephemeroptera), Anisoptera, — *Stenelmis* (Coleoptera) | 44 | 46 | 48 | 50 | .52 |
| — *Gammarus* | 40 | 40 | 40 | 40 | 40 |
| Each species of uncased caddis (excluding *Rhyacophila*), — Zygoptera (excluding *Agrion*) | 38 | 36 | 35 | 33 | 31 |
| Each species of Tricladida | 35 | 33 | 31 | 29 | 25 |
| Genera of Hydracarina | 32 | 30 | 28 | 25 | 21 |
| Each species of Mollusca (excluding *Ancylus*) | 30 | 28 | 25 | 22 | 18 |
| — Chironomids (excluding *C. riparius*) | 28 | 25 | 21 | 18 | 15 |
| Each species of *Glossiphonia* | 26 | 23 | 20 | 16 | 13 |
| Each species of *Asellus* | 25 | 22 | 18 | 14 | 10 |
| Each species of leech (excluding *Glossiphonia, Haemopsis*) | 24 | 20 | 16 | 12 | 8 |
| — *Haemopsis* | 23 | 19 | 15 | 10 | 7 |
| — *Tubifex* sp. | 22 | 18 | 13 | 12 | 9 |
| — *Nais* | 20 | 16 | 10 | 6 | 2 |
| Each of the air-breathing species | 19 | 15 | 9 | 5 | 1 |
| No animal life | | | 0 | | |

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Platts, William S.; Megahan, Walter F.; Minshall, G. Wayne. Methods for evaluating stream, riparian, and biotic conditions. Gen. Tech. Rep. INT-138. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 70 p.

This report develops a standard way of measuring stream, riparian, and biotic conditions and evaluates the validity of the measurements recommended. Accuracy and precision of most measurements are defined. This report will be of value to those persons documenting, monitoring, or predicting stream conditions and their biotic resources, especially those related to impacts from land uses.

KEYWORDS: methods, aquatic habitat, fish, streams, inventory, fish dynamics, riparian, stream channel, macroinvertebrates

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**Intermountain
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General Technical
Report INT-139

February 1983

# Canopy Development in Lodgepole Pine: Implications for Wildlife Studies and Multiple Resource Management

**Dennis M. Cole**

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**DENNIS M. COLE** is a research silviculturist with the Silviculture of Northern Rocky Mountain Subalpine Forest Ecosystems Research Unit at the Forestry Sciences Laboratory, Bozeman, Mont. His studies have focused on lodgepole pine silviculture; particularly growth and yield relationships, culture of immature stands, and management of the species in the face of major insect and disease problems.

# RESEARCH SUMMARY

This report describes how recently developed models of vertical crown development in lodgepole pine (*Pinus contorta* var. *latifolia*) can be used with existing data to facilitate studies of wildlife-forest cover relationships. Instructions are given for obtaining values of stand basal area and average height of dominant trees—from forest inventory data bases or resource aerial photographs, such as those maintained by the National Forest System—and for solving the crown models for stands where wildlife data are available or studies are planned. The report shows how linkage of the models with a computerized stand projection program provides values of present and future effects of alternative timber management prescriptions on several important components of wildlife cover—height to canopy, canopy depth, stand height, and canopy coverage. Beginning at age 20 years, it illustrates these stand effects at 10-year intervals for a duration of 120 years, for five widely different initial stand densities—each subjected to five typical timber management prescriptions. Results and future uses of the canopy models and stand projections including them are discussed in relation to some current concepts of managing thermal cover and the possibilities of refining these concepts.

United States
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**Dennis M. Cole**

## INTRODUCTION

Lodgepole pine (*Pinus contorta* var. latifolia) covers over 17 million acres in the Western United States and nearly three times that amount in western Canada. In the Western United States, 13 million of the 17 million acres are classified as "commercial forest lands" (U.S. Department of Agriculture 1972). This means the land is designated to receive management activities for producing and sustaining timber and other resource values. In a land area of this size, considerable opportunity exists to favor or discourage some resource values in relation to others. Wildlife is a good example of this in relation to timber management activities—some wildlife species are favored by a particular silvicultural activity, while others are disadvantaged. It is important to know much more about the effects of stand manipulations on wildlife than we currently do if we are to achieve better multiresource management of lodgepole pine forests.

Probably more attention has been given to the effects of timber management on big game than on other wildlife, but significant gaps exist in our knowledge of how big game respond to composition and structure of forests (Beall 1976), particularly in regard to winter habitat requirements (Thomas and others 1979). According to Thomas and others (1979), "Each winter range is different in its vegetative mosaic and the way it is used by the animals. The manager should study winter range carefully before deciding if and how to alter cover, particularly thermal cover." As an adjunct to studies of the wildlife behavioral relationships associated with cover versus noncover, the thermal aspects of cover, and the importance of cover juxtaposition on the land, I believe that more attention should be given to depth and position of stand canopies and to how they change with time in both managed and unmanaged forests.

The state-of-the-art in growth and yield simulation of even-aged forest stands now allows forecasts of canopy characteristics from stand parameters that are the objects of silvicultural manipulation. In a related paper (Cole and Jensen 1982), models were presented for describing vertical development of canopies in even-aged lodgepole pine stands. In that work, the rationale and methods used to develop and test the models were covered and examples were given of how the models could be used with computerized stand growth projection programs to preview crown and canopy development under different timber management prescriptions. Such information is of interest not only to big-game managers, but to researchers studying behavioral associations of such diverse wildlife forms as the grizzly bear[1] (*Ursus arctos horribilis*) and nongame birds and mammals.

The objective of this paper is to bring these models to the attention of researchers and managers in the wildlife and forestry disciplines for the following purposes: (1) to point out how they can be used with forest inventory data or data from aerial photos, as a scalar to interpret the data bases in terms of vertical canopy characteristics; (2) to suggest that the extent and duration of canopy position and depth should be tested for correlation with wildlife behavioral traits in general, and cover requirements of big game in particular; and (3) to illustrate and discuss how different management situations and thinning prescriptions influence vertical canopy development in comparison to natural stands.

[1] Knight, Richard. Personal conversation. Bozeman, MT: U.S. Department of the Interior, National Park Service, Interagency Grizzly Bear Team; 1981.

# THE CROWN MODELS

## Estimating Dominant Crown Position of Stands

An interactive model has been developed (Cole and Jensen 1982) that relates average height to the base of the crowns of dominant trees (HBCD) with average height of the dominants (HD), and stand basal area (BA):

$$\hat{HBCD} = \left[\left(1.0019 * e^{-\left|\frac{\frac{BA}{250} - 1.0}{0.716}\right|^{5.5}} - 0.0019\right) * (0.1492 * HD^{1.33})\right] * 0.9786^{2/} \quad [1]$$

where:
$\overline{HBCD} = 23.3$ ft, $R^2 = 0.82$, and $S_{y \cdot x} \cong 5.2$ ft,
and limits are
$50 \leq BA < 250$, and $0 < HD < 120$.

Note: *The above and all following mathematical expressions were developed in English units; therefore, their solutions are correct only with the specified units of the English system. Tables of results are likewise presented in English units.*

This relationship is represented as a response surface in figure 1, and estimated values of HBCD generated from it for ranges of BA and HD are given in table 1.

The model (equation [1]) can be adjusted to data sets from other populations of lodgepole pine trees through a simple least squares fitting of model estimates to observed sample values of HBCD (forcing the regression through the origin) to obtain a least squares scaling coefficient ($b_i$) for each population:

$b_i = \Sigma XY/\Sigma X^2$
where
X = estimated HBCD according to equation [1], and
$Y_i$ = actual HBCD from the pertinent data set.

The value of the coefficient ($b_i$) is used to scale estimates from equation [1] to local conditions as shown in equation [2]:

$$\hat{HBCD}_i = \hat{HBCD} * b_i. \quad [2]$$

## Estimating Dominant Crown Depth of Stands

Equation [1] with [2] provides estimates of the average position (height above ground) of dominant tree crowns in even-aged lodgepole pine stands, as a function of stand density and average height of dominant trees. Average depth (length) of dominant tree crowns can be estimated for a stand, following estimation of HBCD, as the difference between the average height of dominant trees (HD) and HBCD. Although the position and depth of the dominant crown class does not indicate the total depth and position of the stand canopy, dominant crown parameters will probably be more effective than total canopy parameters as indicators of wildlife relationships, because the suppressed tree component of lodgepole pine stands has relatively little influence on the amount and distribution of overall canopy biomass (Gary 1976). This distinction is particularly important in the case of thinned lodgepole pine stands, which are best thinned from below, thereby removing (to varying degrees according to thinning intensity) the lower portions of the overall stand canopy.

[2]Least squares coefficient from fitting the hypothesized relation to the data from which it was partially derived.

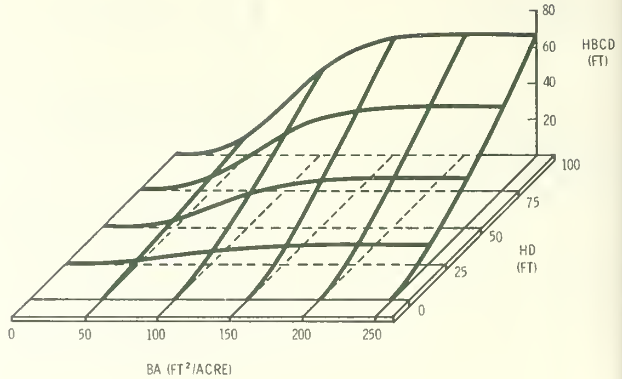


**Figure 1.—Height to base of crown (HBCD) as a function of basal area per acre (BA) in square feet and average height of dominant trees (HD) in feet.**

**Table 1.—** Height to base of crown (HBCD) in feet as a function of basal area per acre (BA) in square feet and average height of dominant trees (HD) in feet[1]

| HD | BA 25 | 50 | 75 | 100 | 125 | 150 | 175+ |
|---|---|---|---|---|---|---|---|
| 10 | – | – | 1 | 2 | 3 | 3 | 3 |
| 20 | – | 1 | 3 | 5 | 7 | 8 | 8 |
| 30 | – | 2 | 6 | 9 | 12 | 13 | 13 |
| 40 | 1 | 3 | 8 | 14 | 17 | 19 | 20 |
| 50 | 1 | 4 | 11 | 18 | 23 | 25 | 26 |
| 60 | 1 | 5 | 14 | 23 | 29 | 32 | 34 |
| 70 | 1 | 7 | 17 | 28 | 36 | 40 | 41 |
| 80 | 1 | 8 | 20 | 34 | 43 | 48 | 49 |
| 90 | 2 | 9 | 24 | 40 | 50 | 56 | 58 |
| 100 | 2 | 10 | 28 | 46 | 58 | 64 | 66 |

[1]Values within the block fall within the range of the basic data.

## Estimating Average Position and Depth of Stand Canopies

Despite the greater relevancy to this paper of the dominant portion of the canopy, estimates of the position and depth of the total canopy are possible because of the relationship (equation [3]) between average height to the base of crowns of suppressed trees (HBCS) and HBCD (Cole and Jensen 1982):

$$HBCS = -4.19 + 0.39\,HBCD + 0.18\,HD \quad [3]$$

$$R^2 = 0.84.$$

Equation [3] can be used, subsequent to estimating HBCD, to obtain an estimate of the position of the overall canopy in relation to height in feet above the ground. Overall depth of the canopy can be calculated then, as the difference between HD and HBCS for the stand.

## CAPITALIZING ON EXISTING RESOURCE DATA

Many data bases already exist to which the equations reported in this paper can be applied. For example, all National Forest Regions maintain a timber management control system and periodically update aerial photography for each National Forest. These systems provide an inventory of the kind, amount, location, and status of the timber resource, and management and natural activities related to it. The Timber Stand Management Record System of USDA Forest Service Region One is a good example of how these systems work.[3] The Region One system is designed to:

a. provide information for silvicultural prescriptions,
b. plan for and schedule treatments,
c. make required reports,
d. keep an historical record of all treatments, and
e. provide information to update and revise the Timber Resource Plan and Harvest Schedule.

To accomplish this the system has three components:

a. index map,
b. stand folder, and
c. automated data base.

All components must be revised (and otherwise maintained) concurrently for the system to work correctly. The index map shows the boundaries of each identified stand in the record system, in relation to surrounding stands and the land base itself. The stand folder (one for each stand) contains all available information for managing the stand, and with reference to the other two components provides the basic data for making silvicultural prescriptions. The automated data base allows compilation and summarization of data obtained through stand examination surveys and other information filed in the stand folder and in return makes reports to the stand folder, thus updating the stand record.

The record system provides a means for accessing map-indexed values of HD and BA for all lodgepole pine stands entered in the system, where these values have been obtained in the stand examination survey. Using these values with the crown models reported here, the resource manager can revise the data base for all lodgepole pine stands to include the position and depth of the canopy for the dominant-tree portion as well as for the total stand canopy.

Not all lodgepole pine stands are yet entered in stand management record systems, and not all that are entered have dominant height and basal area values recorded. Most of the stands that have been entered into the system have been recorded because of a past management activity, such as harvesting or timber stand improvement that had created or modified the stand, or because such an activity was planned for the near future. However, the proportion of currently nonidentified stands should diminish rapidly in the next few years. This is because the National Forest Management Act requires that all timber management activities must be preceded by a silvicultural prescription that calls for that activity specifically or accommodates the activity naturally in the course of a larger prescription. Until all existing lodgepole pine stands are entered into the system and supported by stand examination data, including average height of dominant trees (HD) and stand basal area (BA), a supplemental source of information for these values is necessary. Controlled aerial photography can provide this alternative.

With the comprehensive and current aerial photo coverage available for all National Forests, lodgepole pine stands can be identified and delineated, and values of HD and BA can be determined photogrammetrically for any area in a National Forest. Thus, when the needed data on HD and BA are not available in the automated data base of the Timber Stand Management Record System, it can be obtained from available aerial photos for subsequent use in the crown models reported in this paper. These data and derived canopy estimates can also be added to the information in the stand folder of the Timber Management Record System.

## BIG-GAME COVER CONCEPTS

Threshold values of area, canopy coverage, and attained height are the stand characteristics currently given greatest weight in attempts to define cover for mule deer and elk (Thomas and others 1979), and in attempts to determine the importance of cover to various habitat requirements of those species (fig. 2 and 3). For example, thermal cover for deer and elk is defined as a stand of coniferous trees 40 ft or more tall with average crown cover exceeding 70 percent (Black and others 1976). While these threshold values undoubtedly have some merit for discriminating between stands that do and do not provide suitable resting environments for summering elk and mule deer, they cannot provide a quantitative basis for further differentiating the thermal quality of summer environments—nor can they even identify winter thermal cover for elk.

Obviously, different silvicultural prescriptions create different stand conditions, which in turn can differentially influence the environments and behavior of wildlife. However, not enough is known about how specific silvicultural manipulations change stand structure and canopy characteristics—e.g., thermal aspects of the stands—and how these changes affect wildlife. Reifsnyder and Lull (1965) have compiled a thorough monograph on radiant energy in relation to forests. They discuss the components of radiant energy, the physical laws involved in the absorption and transmission of it in the forest, the measurement of these processes, and their general relationship with canopy components discussed in this paper. Workers interested in interpreting canopy values and changes in them, in terms of thermal implications, will find the Reifsnyder and Lull monograph a valuable reference.

Multistoried stands are considered better for cover than single-storied stands; however, if only single-storied stands are considered (as in this paper), dense stands with low canopies are better than lightly stocked stands with high canopies (Thomas and others 1979). These general concepts can be kept in mind as the reader examines the examples presented in the following section on the effect of some different lodgepole pine management prescriptions on canopy characteristics and timber size and yield.

[3]Timber Management Control Handbook, FSH 2409.21e, R-1 Amend. 9, 1980.

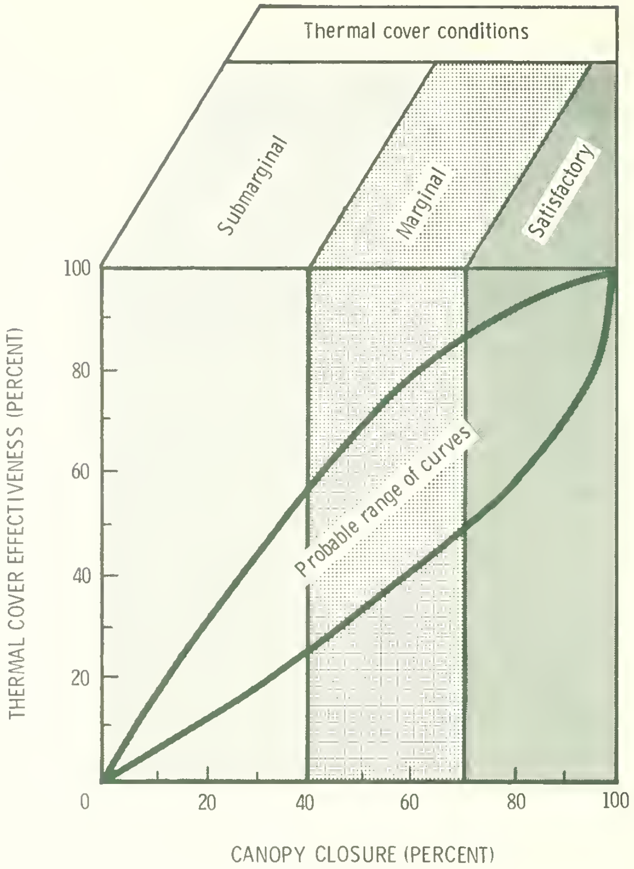


**Figure 2.—Relationship of canopy closure to effectiveness of thermal cover for deer and elk (from Thomas and others 1979).**

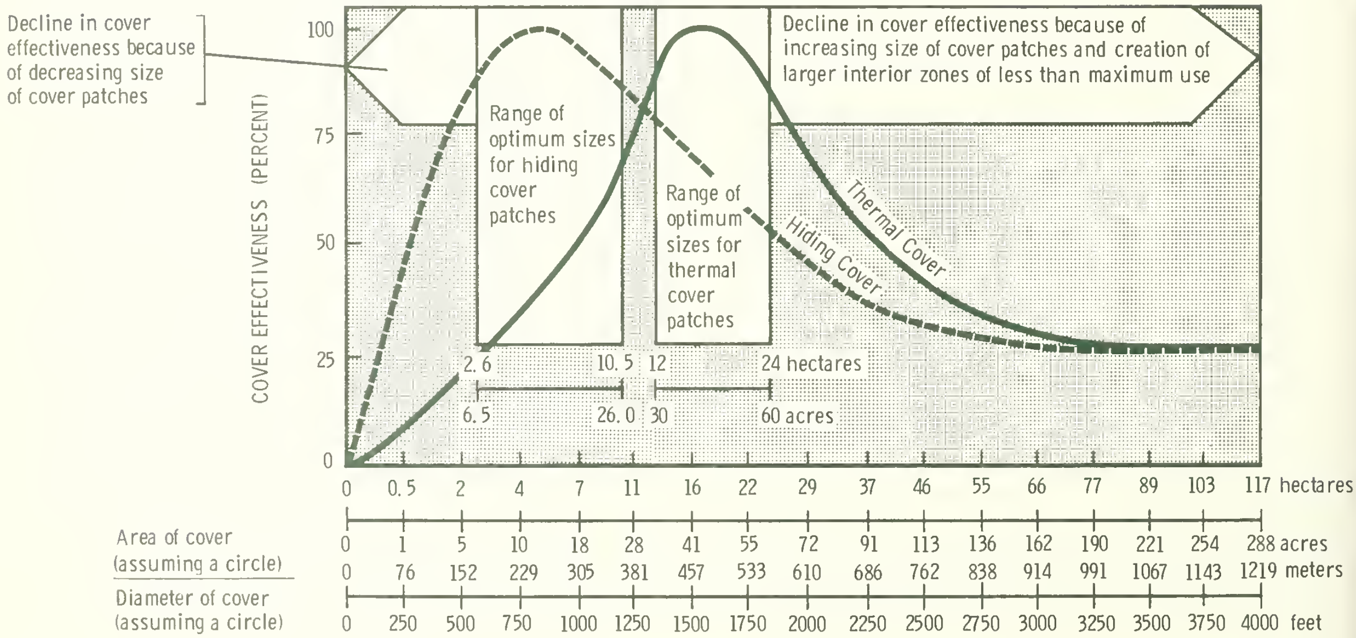


**Figure 3.—Effectiveness of various sizes of hiding and thermal cover areas on summer and spring-fall ranges in the Blue Mountains. The range of optimum sizes for patches of hiding cover are derived from figure 60 in Thomas and others 1979.**

## FORECASTING COVER CHARACTERISTICS OF LODGEPOLE PINE STANDS

To estimate the vertical position and depth of stand canopies in the future, reliable estimates of dominant height (HD) and basal area (BA) must be possible for future ages. Realistic values of these parameters can be obtained with computerized tree and stand growth projections for lodgepole pine (Stage 1973; Myers and others 1971; Edminster 1978). The models reported here can also be imbedded in such computer programs to provide vertical crown development information in addition to other forecasts. We (Cole and Jensen 1982) did this with a stand projection computer program for lodgepole pine[4] (Myers and others 1971), modified to apply to development of natural as well as managed stands and to include growth equations developed from Montana and Idaho stand data (Cole 1971; Cole and Stage 1972; Stage 1975). In the Cole and Jensen paper, we give an example of vertical crown development, along with development of other important stand parameters for thinned versus unthinned stands of moderate and extreme initial stand densities.

In this paper, examples of projected canopy development for an increased number of management situations in lodgepole pine are shown (tables 2 through 6). Each table reflects the response of a specific stand density at age 20 years to several typical management prescriptions for lodgepole pine stands—as viewed through stand development to age 140 years. Although representative, these examples are only a small proportion of the large number of combinations of biological situations and management prescriptions that can be considered. The stand densities chosen were 500, 1,000, 2,000, 4,000, and 8,000 trees per acre at age 20 years. Five management situations were compared for each stand density:

[4]This program entitled "LP STAND GRO" is available from the author, upon request.

**Table 2.**— Lodgepole pine stand characteristics, from ages 20 to 140 years of initial stocking at age 20 of 500 trees/acre, under different management situations, on site index$_{100}$ = 60 lands in Montana and Idaho

| Age | Management situation[1] | Number trees/ acre | Average stand diameter | Basal area | CCF | Average dominant height | Dominant crown height | Dominant crown length | Net merchantable volume[2] | Merchantable volume cut |
|---|---|---|---|---|---|---|---|---|---|---|
| Yrs | | | Inches | Ft$^2$ | | Ft | | | Ft$^3$ | |
| 20 | N | 500 | 3.2 | 28 | 48 | 15 | 1 | 14 | — | — |
| | P | — | — | — | — | — | — | — | — | — |
| | P + C100 | — | — | — | — | — | — | — | — | — |
| | P + C120 | — | — | — | — | — | — | — | — | — |
| | DMT | 333 | 2.7 | 13 | 26 | 14 | 1 | 13 | — | — |
| 50 | N | 483 | 6.0 | 95 | 110 | 34 | 10 | 24 | 1,090 | — |
| | P | — | — | — | — | — | — | — | — | — |
| | P + C100 | — | — | — | — | — | — | — | — | — |
| | P + C120 | — | — | — | — | — | — | — | — | — |
| | DMT | 327 | 6.7 | 80 | 88 | 34 | 8 | 26 | 1,020 | — |
| 80 | N | 435 | 7.4 | 130 | 137 | 48 | 22 | 26 | 2,480 | — |
| | P | — | — | — | — | — | — | — | — | — |
| | P + C100 | — | — | — | — | — | — | — | — | — |
| | P + C120 | — | — | — | — | — | — | — | — | — |
| | DMT | 290 | 8.3 | 109 | 110 | 48 | 19 | 29 | 2,150 | — |
| 110 | N | 372 | 8.6 | 150 | 149 | 60 | 32 | 28 | 3,750 | — |
| | P | — | — | — | — | — | — | — | — | — |
| | P + C100 | — | — | — | — | — | — | — | — | — |
| | P + C120 | — | — | — | — | — | — | — | — | — |
| | DMT | 200 | 9.5 | 98 | 94 | 56 | 22 | 34 | 2,340 | — |
| 140 | N | 307 | 9.6 | 154 | 147 | 69 | 39 | 30 | 4,550 | — |
| | P | — | — | — | — | — | — | — | — | — |
| | P + C100 | — | — | — | — | — | — | — | — | — |
| | P + C120 | — | — | — | — | — | — | — | — | — |
| | DMT | 118 | 10.5 | 71 | 66 | 59 | 22 | 37 | 2,340 | — |

[1]Management situation: N = no thinning, P = precommercial thinning at age 20 to growing stock level (GSL) 80 (Myers 1967), P + C100 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 100, P + C120 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 120, DMT = dwarf mistletoe-infected stand with dwarf mistletoe control thinning at age 20.
[2]Merchantable cubic feet is volume in trees 4.6 inches d.b.h. and larger, to 4.0-inch top.

Table 3.—Lodgepole pine stand characteristics, from ages 20 to 140 years of initial stocking at age 20 of 1,000 trees/acre, under different management situations, on site index$_{100}$ = 60 lands in Montana and Idaho

| Age | Management situation[1] | Number trees/ acre | Average stand diameter | Basal area | CCF | Average dominant height | Dominant crown height | Dominant crown length | Net merchantable volume[2] | Merchantable volume cut |
|---|---|---|---|---|---|---|---|---|---|---|
| *Yrs* | | | *Inches* | *Ft²* | | *Ft* | | | *Ft³* | |
| 20 | N | 1,000 | 2.8 | 43 | 82 | 15 | 1 | 14 | — | — |
| | P | 457 | 3.3 | 27 | 46 | 16 | 1 | 15 | — | — |
| | P + C100 | 457 | 3.3 | 27 | 46 | 16 | 1 | 15 | — | — |
| | P + C120 | 457 | 3.3 | 27 | 46 | 16 | 1 | 15 | — | — |
| | DMT | 664 | 2.3 | 19 | 44 | 14 | 1 | 13 | — | — |
| 50 | N | 933 | 4.8 | 117 | 153 | 33 | 13 | 20 | 830 | — |
| | P | 441 | 6.2 | 92 | 102 | 35 | 10 | 25 | 1,140 | — |
| | P + C100 | 327 | 6.6 | 78 | 86 | 35 | 10 | 25 | 1,010 | 130 |
| | P + C120 | 412 | 6.3 | 89 | 101 | 35 | 10 | 25 | 1,120 | 20 |
| | DMT | 640 | 5.3 | 98 | 121 | 34 | 10 | 24 | 930 | — |
| 80 | N | 784 | 6.0 | 154 | 179 | 47 | 24 | 23 | 2,510 | — |
| | P | 399 | 7.7 | 129 | 129 | 49 | 23 | 26 | 2,570 | — |
| | P + C100 | 227 | 8.8 | 96 | 94 | 50 | 21 | 29 | 2,010 | 340 |
| | P + C120 | 301 | 8.2 | 110 | 112 | 50 | 23 | 27 | 2,250 | 240 |
| | DMT | 562 | 6.7 | 138 | 151 | 47 | 23 | 24 | 2,450 | — |
| 110 | N | 626 | 6.9 | 163 | 177 | 59 | 32 | 27 | 3,700 | — |
| | P | 343 | 8.9 | 148 | 148 | 61 | 33 | 28 | 3,810 | — |
| | P + C100 | 157 | 10.8 | 100 | 92 | 62 | 29 | 33 | 2,690 | 450 |
| | P + C120 | 224 | 9.9 | 120 | 113 | 62 | 31 | 31 | 3,160 | 290 |
| | DMT | 398 | 7.7 | 129 | 133 | 56 | 27 | 29 | 2,890 | — |
| 140 | N | 498 | 7.8 | 165 | 170 | 68 | 39 | 29 | 4,590 | — |
| | P | 284 | 9.9 | 152 | 152 | 70 | 40 | 30 | 4,590 | — |
| | P + C100 | 142 | 12.2 | 115 | 102 | 71 | 35 | 36 | 3,620 | — |
| | P + C120 | 196 | 11.1 | 132 | 120 | 71 | 38 | 33 | 4,060 | — |
| | DMT | 234 | 8.5 | 92 | 92 | 59 | 27 | 32 | 2,890 | — |

[1]Management situation: N = no thinning, P = precommercial thinning at age 20 to growing stock level (GSL) 80 (Myers 1967), P + C100 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 100, P + C120 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 120, DMT = dwarf mistletoe-infected stand with dwarf mistletoe control thinning at age 20.
[2]Merchantable cubic feet is volume in trees 4.6 inches d.b.h. and larger, to 4.0-inch top.

**Table 4.**— Lodgepole pine stand characteristics, from ages 20 to 140 years of initial stocking at age 20 of 2,000 trees/acre, under different management situations, on site $index_{100}$ = 60 lands in Montana and Idaho

| Age | Management situation[1] | Number trees/ acre | Average stand diameter | Basal area | CCF | Average dominant height | Dominant crown height | Dominant crown length | Net merchantable volume[2] | Merchantable volume cut |
|---|---|---|---|---|---|---|---|---|---|---|
| *Yrs* | | | *Inches* | *Ft²* | | *Ft* | *Ft* | *Ft* | *Ft³* | *Ft³* |
| 20 | N | 2,000 | 2.4 | 63 | 137 | 14 | 1 | 13 | — | — |
| | P | 473 | 3.1 | 25 | 44 | 16 | 1 | 15 | — | — |
| | P + C100 | 473 | 3.1 | 25 | 44 | 16 | 1 | 15 | — | — |
| | P + C120 | 473 | 3.1 | 25 | 44 | 16 | 1 | 15 | — | — |
| | DMT | 1,392 | 2.0 | 30 | 79 | 13 | 1 | 12 | — | — |
| 50 | N | 1,525 | 3.9 | 127 | 189 | 31 | 12 | 19 | — | — |
| | P | 458 | 6.1 | 93 | 107 | 35 | 10 | 25 | 1,130 | — |
| | P + C100 | 332 | 6.5 | 77 | 85 | 36 | 10 | 26 | 990 | 140 |
| | P + C120 | 412 | 6.3 | 89 | 101 | 35 | 10 | 25 | 1,120 | 10 |
| | DMT | 1,007 | 4.3 | 102 | 142 | 32 | 10 | 22 | — | — |
| 80 | N | 1,163 | 5.0 | 159 | 203 | 45 | 23 | 22 | 1,810 | — |
| | P | 415 | 7.5 | 127 | 133 | 49 | 23 | 26 | 2,520 | — |
| | P + C100 | 227 | 8.8 | 96 | 94 | 50 | 22 | 28 | 2,020 | 370 |
| | P + C120 | 301 | 8.2 | 110 | 112 | 50 | 23 | 27 | 2,270 | 230 |
| | DMT | 748 | 5.7 | 133 | 158 | 45 | 21 | 24 | 1,920 | — |
| 110 | N | 888 | 5.9 | 169 | 197 | 57 | 31 | 26 | 3,280 | — |
| | P | 358 | 8.7 | 148 | 146 | 61 | 33 | 28 | 3,800 | — |
| | P + C100 | 157 | 10.8 | 100 | 92 | 63 | 29 | 34 | 2,700 | 450 |
| | P + C120 | 224 | 9.9 | 120 | 113 | 62 | 32 | 30 | 3,180 | 290 |
| | DMT | 499 | 6.7 | 122 | 134 | 52 | 24 | 28 | 2,410 | — |
| 140 | N | 681 | 6.8 | 172 | 188 | 66 | 38 | 28 | 4,370 | — |
| | P | 298 | 9.7 | 153 | 145 | 70 | 40 | 30 | 4,620 | — |
| | P + C100 | 142 | 12.2 | 115 | 102 | 72 | 35 | 37 | 3,630 | — |
| | P + C120 | 196 | 11.1 | 132 | 120 | 71 | 38 | 33 | 4,080 | — |
| | DMT | 293 | 7.6 | 92 | 96 | 56 | 24 | 32 | 2,410 | — |

[1]Management situation: N = no thinning, P = precommercial thinning at age 20 to growing stock level (GSL) 80 (Myers 1967), P + C100 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 100, P + C120 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 120, DMT = dwarf mistletoe-infected stand with dwarf mistletoe control thinning at age 20.

[2]Merchantable cubic feet is volume in trees 4.6 inches d.b.h. and larger, to 4.0-inch top.

Table 5.—Lodgepole pine stand characteristics, from ages 20 to 140 years of initial stocking at age 20 of 4,000 trees/acre, under different management situations, on site index$_{100}$ = 60 lands in Montana and Idaho

| Age | Management situation[1] | Number trees/ acre | Average stand diameter | Basal area | CCF | Average dominant height | Dominant crown height | Dominant crown length | Net merchantable volume[2] | Merchantable volume cut |
|---|---|---|---|---|---|---|---|---|---|---|
| *Yrs* | | | *Inches* | *Ft²* | | *Ft* | | | *Ft³* | |
| 20 | N | 4,000 | 1.6 | 56 | 183 | 12 | 1 | 11 | — | — |
| | P | 539 | 2.3 | 16 | 35 | 15 | 1 | 14 | — | — |
| | P + C100 | 539 | 2.3 | 16 | 35 | 15 | 1 | 14 | — | — |
| | P + C120 | 539 | 2.3 | 16 | 35 | 15 | 1 | 14 | — | — |
| | DMT | 3,037 | 1.3 | 28 | 117 | 11 | 1 | 10 | — | — |
| 50 | N | 3,050 | 3.0 | 150 | 271 | 29 | 12 | 17 | — | — |
| | P | 523 | 5.7 | 93 | 110 | 35 | 10 | 25 | 1,050 | — |
| | P + C100 | 349 | 6.2 | 73 | 84 | 36 | 10 | 26 | 920 | 130 |
| | P + C120 | 433 | 6.0 | 85 | 99 | 36 | 10 | 26 | 1,030 | 20 |
| | DMT | 2,233 | 3.1 | 117 | 206 | 30 | 11 | 19 | — | — |
| 80 | N | 2,131 | 3.9 | 177 | 264 | 44 | 22 | 22 | — | — |
| | P | 472 | 7.1 | 130 | 139 | 50 | 23 | 27 | 2,510 | — |
| | P + C100 | 239 | 8.5 | 94 | 94 | 50 | 21 | 29 | 1,970 | 350 |
| | P + C120 | 312 | 8.0 | 109 | 111 | 50 | 23 | 27 | 2,230 | 270 |
| | DMT | 1,255 | 4.3 | 127 | 177 | 43 | 19 | 24 | — | — |
| 110 | N | 1,455 | 4.8 | 183 | 239 | 55 | 30 | 25 | 2,240 | — |
| | P | 403 | 8.3 | 151 | 152 | 61 | 33 | 28 | 3,850 | — |
| | P + C100 | 163 | 10.6 | 100 | 92 | 63 | 30 | 33 | 2,710 | 480 |
| | P + C120 | 232 | 9.7 | 119 | 113 | 62 | 32 | 30 | 3,160 | 300 |
| | DMT | 742 | 5.4 | 118 | 145 | 51 | 23 | 28 | 1,800 | — |
| 140 | N | 1,028 | 5.7 | 182 | 217 | 64 | 37 | 27 | 3,840 | — |
| | P | 332 | 9.3 | 157 | 151 | 70 | 41 | 29 | 4,700 | — |
| | P + C100 | 147 | 12.0 | 115 | 103 | 72 | 35 | 37 | 3,640 | — |
| | P + C120 | 204 | 10.9 | 132 | 121 | 71 | 38 | 33 | 4,100 | — |
| | DMT | 436 | 6.3 | 94 | 107 | 55 | 23 | 32 | 1,860 | — |

[1]Management situation: N = no thinning, P = precommercial thinning at age 20 to growing stock level (GSL) 80 (Myers 1967), P + C100 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 100, P + C120 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 120, DMT = dwarf mistletoe-infected stand with dwarf mistletoe control thinning at age 20.

[2]Merchantable cubic feet is volume in trees 4.6 inches d.b.h. and larger, to 4.0-inch top.

**Table 6.**— Lodgepole pine stand characteristics, from ages 20 to 140 years of initial stocking at age 20 of 8,000 trees/acre, under different management situations, on site $index_{100}$ = 60 lands in Montana and Idaho

| Age | Management situation[1] | Number trees/ acre | Average stand diameter | Basal area | CCF | Average dominant height | Dominant crown height | Dominant crown length | Net merchantable volume[2] | Merchantable volume cut |
|---|---|---|---|---|---|---|---|---|---|---|
| *Yrs* | | | *Inches* | *Ft²* | | *Ft* | | | *Ft³* | |
| 20 | N | 8,000 | 1.4 | 86 | 327 | 10 | 2 | 8 | — | — |
| | P | 539 | 2.3 | 16 | 35 | 14 | 2 | 12 | — | — |
| | P + C100 | 539 | 2.3 | 16 | 35 | 14 | 2 | 12 | — | — |
| | P + C120 | 539 | 2.3 | 16 | 35 | 14 | 2 | 12 | — | — |
| | DMT | 8,000 | 1.4 | 86 | 327 | 10 | 2 | 8 | — | — |
| 50 | N | 5,664 | 2.4 | 178 | 389 | 26 | 11 | 15 | — | — |
| | P | 523 | 5.7 | 93 | 110 | 34 | 10 | 24 | 1,010 | — |
| | P + C100 | 349 | 6.2 | 73 | 84 | 35 | 10 | 25 | 890 | 120 |
| | P + C120 | 433 | 6.0 | 85 | 99 | 34 | 10 | 24 | 990 | 20 |
| | DMT | 1,254 | 1.6 | 18 | 57 | 23 | 11 | 12 | — | — |
| 80 | N | 3,281 | 3.3 | 195 | 327 | 41 | 20 | 21 | — | — |
| | P | 472 | 7.1 | 130 | 139 | 48 | 23 | 25 | 2,450 | — |
| | P + C100 | 239 | 8.5 | 94 | 94 | 49 | 21 | 28 | 1,930 | 340 |
| | P + C120 | 312 | 8.0 | 109 | 111 | 49 | 22 | 27 | 2,180 | 260 |
| | DMT | 908 | 4.3 | 92 | 128 | 38 | 11 | 27 | — | — |
| 110 | N | 1,998 | 4.2 | 192 | 273 | 52 | 28 | 24 | — | — |
| | P | 403 | 8.3 | 151 | 152 | 60 | 33 | 27 | 3,780 | — |
| | P + C100 | 163 | 10.6 | 100 | 92 | 62 | 29 | 33 | 2,660 | 480 |
| | P + C120 | 232 | 9.7 | 119 | 113 | 61 | 31 | 30 | 3,100 | 290 |
| | DMT | 778 | 5.7 | 138 | 164 | 48 | 24 | 24 | 2,170 | — |
| 140 | N | 1,324 | 5.1 | 188 | 237 | 61 | 35 | 26 | 3,080 | — |
| | P | 332 | 9.3 | 157 | 151 | 69 | 40 | 29 | 4,630 | — |
| | P + C100 | 147 | 12.0 | 115 | 103 | 71 | 34 | 37 | 3,580 | — |
| | P + C120 | 204 | 10.9 | 132 | 121 | 70 | 38 | 32 | 4,030 | — |
| | DMT | 519 | 6.7 | 127 | 140 | 54 | 26 | 28 | 2,610 | — |

[1]Management situation: N = no thinning, P = precommercial thinning at age 20 to growing stock level (GSL) 80 (Myers 1967), P + C100 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 100, P + C120 = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 120, DMT = dwarf mistletoe-infected stand with dwarf mistletoe control thinning at age 20.
[2]Merchantable cubic feet is volume in trees 4.6 inches d.b.h. and larger, to 4.0-inch top.

1. N = natural stand development of dwarf mistletoe-free stands,

2. P = precommercial low thinning[5] of dwarf mistletoe-free stands at age 20 to growing stock level[6] 80 (GSL-80),

3. P + C100 = same as item 2, plus subsequent low thinning at 30-year intervals to GSL-100,

4. P + C120 = same as item 2, plus subsequent low thinning at 30-year intervals to GSL-120, and

5. DMT = dwarf mistletoe control thinning, either at age 20 or 50, of dwarf mistletoe-infested stands. This type of thinning will be discussed in more detail, later in this section.

## Results

Tables 2 through 6 show differences in stand development effects among the different initial stand densities for a given prescription, and among prescriptions for a given stand density. To allow better comparison of the position and depth of the dominant canopy as well as of canopy coverage, values from tables 3 through 6 are graphically displayed in figures 4 through 7 for stand densities at age 20 years, of 1,000, 2,000, 4,000, and 8,000 trees per acre, respectively. A graph was not developed for table 2 (500 trees per acre) because most prescriptions were not applicable to this low initial stand density.

In figures 4 through 7, the dashed lines indicate the average crown length and position of dominant trees in the stand for prescriptions resulting in canopy cover of less than 100 percent, as determined by values of less than 100 for Crown Competition Factor (CCF) (Krajicek and others 1961; Alexander and others 1967). The solid lines indicate crown length and position when CCF values are greater than 100, hence canopy coverage exceeds 100 percent. Although CCF cannot serve as a continuous scale measure of crown closure (Krajicek and others 1961), it can indicate the point of 100 percent canopy coverage. This occurs at a CCF value of 100. At higher values of CCF, the stand has complete canopy coverage—but how much more than 100 percent cannot be determined from the CCF value. Similarly, at values less than CCF 100, we know the stand has less than 100 percent of the ground area covered by crowns.

Although figures 4 through 7 distinguish between canopy cover of greater and less than 100 percent, and the current thermal cover definition specifies crown cover of 70 percent or greater, any cover is better than no cover for wintering game (Thomas and others 1979). For this reason, the CCF values calculated in LP STAND GRO are included for each prescription (tables 2 through 6), at each interval of stand development—so as to be available for interpretation by wildlife researchers as an indicator of crown density.

In considering the cover implications of tables 2 through 6 and figures 4 through 7, it is important to remember that the projected stand characteristics are for typically even-aged, single-storied lodgepole pine stands on lands having 100-year site indexes of about 60 ft. Projections for different quality sites indicate differences in crown development, particularly in attained heights.

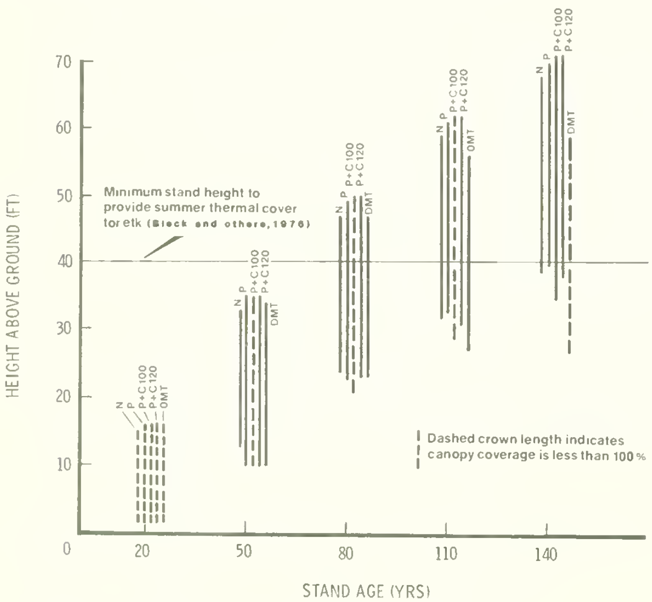


Figure 4.—Development of height, depth, and position of the dominant canopy—in thinned and unthinned stands: initial stocking, age 20 years = 1,000 trees per acre (see table 3).

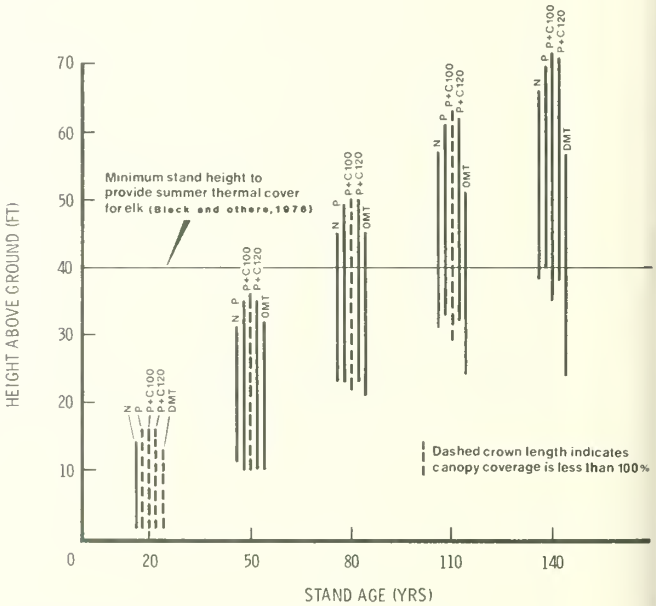


Figure 5.—Development of height, depth, and position of the dominant canopy—in thinned and unthinned stands: initial stocking, age 20 years = 2,000 trees per acre (see table 4).

[5] Low thinning—a method of thinning in which trees of the lowest crown classes are killed first (usually by cutting); with removal of trees of successively higher crown classes, until the desired severity of thinning is attained.

[6] Growing stock level (GSL)—a numerical growing stock index, representing the expected basal area of the subject stand when the tree of average basal area reaches 10 inches d.b.h. (Myers 1967). It is useful for indicating stand density both before and after thinning; hence it is used as an indication of thinning severity.

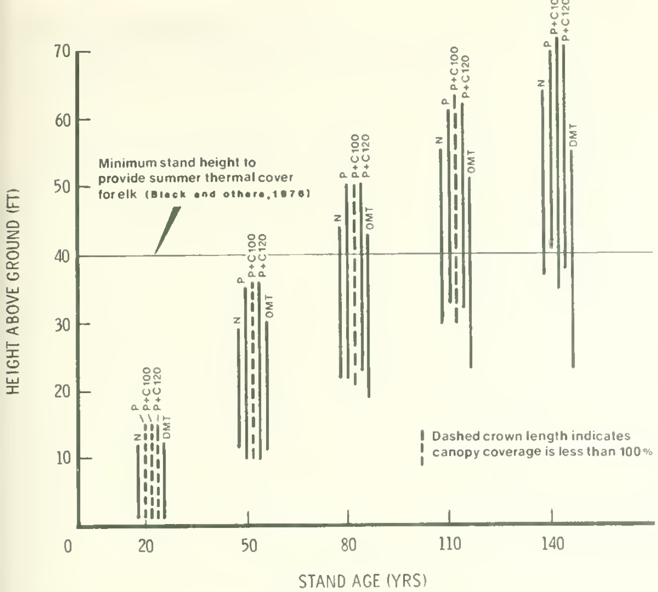


Figure 6.—Development of height, depth, and position of the dominant canopy—in thinned and unthinned stands: initial stocking, age 20 years = 4,000 trees per acre (see table 5).

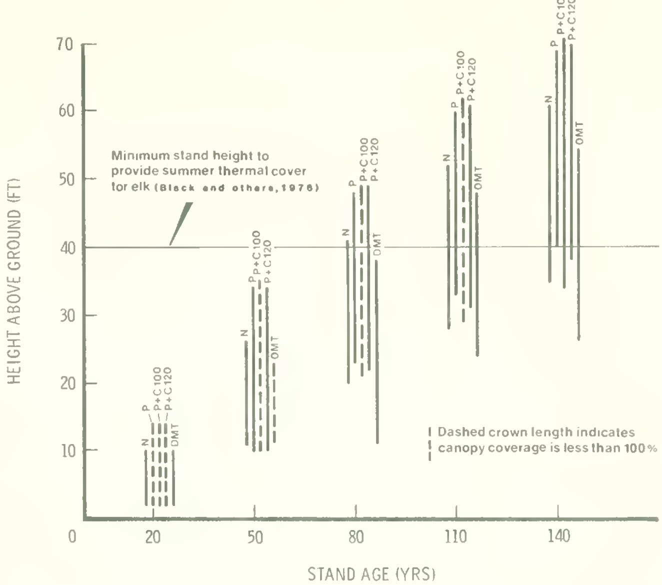


Figure 7.—Development of height, depth, and position of the dominant canopy—in thinned and unthinned stands: initial stocking, age 20 years = 8,000 trees per acre (see table 6).

Heights of dominant lodgepole pine trees increase with age and site index, but are suppressed by higher stand densities. This is illustrated in tables 7 and 8 where CCF 125 represents moderate stand density and CCF 400 represents high stand density (Alexander and others 1967). The boundary line in each table separates the age and site index classes which do and do not provide the minimum height (40 ft) for satisfactory summer thermal cover for mule deer and elk—as currently defined. A general indication of how stand density and thinning in lodgepole pine might influence this thermal cover factor is seen in comparing the ages when the stand reaches the 40-ft threshold, for the different stand density (CCF) levels represented by the two tables.

A more comprehensive indication of thinning effects on stand height as well as on other canopy characteristics is shown in figures 4 through 7, where four different initial stocking levels are illustrated. A comparison of natural stand development among the different stocking levels at each of the given ages shows, again, that height and crown length are reduced with increasing stand density. The effect of thinning on crown development can be seen in each of the figures, by comparing the various thinning prescriptions with the no-thinning situation. It is noteworthy that the thinning prescription resulting in greatest attained height and depth of the canopy (P + C100), accomplishes this at the expense of less than 100 percent canopy coverage (as shown by the dashed line in the figures).

Among thinning prescriptions, however, there do not appear to be large differences in canopy development—with the exception of the dwarf mistletoe thinning (DMT) prescription, where stand height and height to canopy are both reduced.

Dwarf mistletoe (*Arceuthobium americanum*) infection in lodgepole pine reduces tree growth, especially height (Hawksworth and Hinds 1964). Myers and others (1971) indicate this effect in unmanaged stands, over a rotation, can result in a 10 to 30 percent reduction in stand height—depending on time and severity of the infection. An indication of the canopy effects of management response to this serious disease of lodgepole pine is shown by prescription DMT in tables 2 through 6 and figures 4 through 7. Prescription DMT is a dwarf mistletoe control thinning (Myers and others 1971) that removes varying numbers of large and small trees in the stand, depending on stand density and the history of stand infection. With the exception of high initial stocking levels (fig. 7), where attained heights of dominants are kept from reaching the 40-foot threshold until past 80 years of age, the DMT treatments appear to maintain canopy coverage and depth about as well as any of the other management prescriptions compared. However, the consistently lower position of the canopy, of stands receiving mistletoe control thinning, is evident in the graphs (fig. 4 through 7). How canopy position effects thermal qualities of lodgepole pine canopies and wildlife must be resolved by specific studies.

**Table 7.**—Heights of dominant trees at CCF levels of 125 or less for site index classes 30 to 100 by decadal ages 30 to 140 years[1]

| Total age (years) | Site index class 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| | *Height in feet* | | | | | | | |
| 30 | 16 | 20 | 24 | 28 | 32 | 36 | 40 | 45 |
| 40 | 18 | 23 | 28 | 34 | 39 | 44 | 49 | 55 |
| 50 | 20 | 26 | 32 | 39 | 45 | 51 | 58 | 64 |
| 60 | 22 | 29 | 36 | 44 | 51 | 58 | 65 | 72 |
| 70 | 24 | 32 | 40 | 48 | 56 | 64 | 72 | 80 |
| 80 | 26 | 35 | 44 | 52 | 61 | 70 | 79 | 88 |
| 90 | 28 | 37 | 47 | 56 | 66 | 75 | 85 | 94 |
| 100 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 110 | 32 | 42 | 52 | 63 | 73 | 84 | 94 | 104 |
| 120 | 34 | 44 | 55 | 66 | 76 | 87 | 98 | 108 |
| 130 | 35 | 46 | 57 | 68 | 79 | 90 | 101 | 111 |
| 140 | 37 | 48 | 59 | 70 | 81 | 92 | 103 | 114 |

[1]From Alexander and others 1967.

**Table 8.**—Heights of dominant trees at CCF 400 for site index classes 30 to 100 by decadal ages 30 to 140 years[1]

| Total age (years) | Site index class 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|
| | *Height in feet* | | | | | | | |
| 30 | 9 | 11 | 13 | 15 | 17 | 18 | 20 | 22 |
| 40 | 11 | 14 | 17 | 20 | 23 | 26 | 29 | 32 |
| 50 | 13 | 17 | 21 | 25 | 29 | 33 | 37 | 41 |
| 60 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 70 | 17 | 23 | 29 | 35 | 40 | 46 | 52 | 58 |
| 80 | 19 | 26 | 32 | 39 | 45 | 52 | 59 | 65 |
| 90 | 21 | 28 | 36 | 43 | 50 | 57 | 64 | 72 |
| 100 | 23 | 31 | 39 | 46 | 54 | 62 | 70 | 77 |
| 110 | 25 | 33 | 41 | 49 | 57 | 66 | 74 | 82 |
| 120 | 27 | 35 | 44 | 52 | 60 | 69 | 77 | 86 |
| 130 | 28 | 37 | 46 | 54 | 63 | 72 | 80 | 89 |
| 140 | 30 | 39 | 48 | 56 | 65 | 74 | 83 | 92 |

[1]From Alexander and others 1967.

## Conclusions

In total, these stand projections suggest that low thinnings of overstocked even-aged lodgepole pine stands will not result in long-term impairment of the vertical dimension of thermal cover (as currently defined). Such thinnings might even provide and maintain it better. However, this possibility needs to be weighed against the potential for reducing crown coverage too much with some thinnings. These questions need to be resolved by wildlife studies designed to observe the extent and duration of possible offsetting factors occurring in thinned stands.

The situation of uneven-aged and multistoried lodgepole pine stands, such as resulting from cyclic mountain pine beetle (*Dendroctonus ponderosae* Hopk.) infestations of mature and overmature stands obviously involves different cover implications than those discussed. When the changes in stand structure wrought by periodic mountain pine beetle infestations can be reliably incorporated in LP STAND GRO, this factor can also be considered in examining different silvicultural options for managing canopy characteristics of lodgepole pine.

All of the effects discussed here should be of interest to wildlife researchers and forest managers. Other stand development effects included in tables 2 through 6 are average stand diameters by basal areas, and merchantable volumes. These indications of tree size and yield are important to timber planners and managers interested in examining the amount and value of timber yields that are associated with management prescriptions being considered for wildlife cover enhancement.

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Cole, Dennis M. Canopy development in lodgepole pine: implications for wildlife studies and multiple resource management. Gen. Tech. Rep. INT-139. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 13 p.

Describes the use of lodgepole pine crown development models with computerized stand projection programs for examining the effects of alternative timber management prescriptions on canopy characteristics important to wildlife. Instructions are given for exploiting existing data bases with the crown models; and for using the models and procedures to test and refine current forest wildlife cover concepts.

KEYWORDS: canopy development, wildlife cover, thermal cover, canopy characteristics, lodgepole pine, *Pinus contorta*

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General Technical
Report INT-140

March 1983

# A Cavity-Nesting Bird Bibliography—Including Related Titles on Forest Snags, Fire, Insects, Disease, and Decay

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## THE AUTHORS

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**B. RILEY McCLELLAND** is an associate professor of forestry at the University of Montana. He recently completed a major study of the relationships between cavity-nesting birds, forest snags, and decay in western Montana larch/Douglas-fir forests. This bibliography is a byproduct of that study. Dr. McClelland earned his B.S. and M.S. degrees at Colorado State University, Fort Collins. He was awarded a Ph.D. by the University of Montana, Missoula, in 1977. Dr. McClelland also a National Park Service ecologist is currently studying the bald eagle at Glacier National Park, MT.

## RESEARCH SUMMARY

This report provides an index to the contents of more than 1,700 references pertaining to cavity-nesting birds and the related topics of forest snags, fire, insects, disease, and decay.

The list of titles is arranged alphabetically by author and each title is assigned a reference number. The reference number identifies the title in the indexes provided.

The indexes include a forest snag index; a fire, insect, disease, and decay index; a cavity-nesting bird index; and a geographic index.

The cavity-nesting bird index contains separate sections for each of 86 different bird species. Keywords used are: habitat management, habitat, foraging behavior, breeding, nesting, nest and roost trees, nest boxes and houses, biology, ecology, life history, relations with other fauna, territory, distribution, population density, status, identification, taxonomy, and damage.

## ACKNOWLEDGMENT

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# CONTENTS

# THE BIBLIOGRAPHY

The bibliography is organized in three major parts: the numbered list of titles, the subject matter indexes, and the geographic index.

## The List of Titles and Reference Numbers

The list of titles is arranged alphabetically and is numbered consecutively.

## The Subject Matter Indexes

Three subject matter indexes are provided. The first deals with forest snags; the second with fire, insects, desease, and decay; and the third with cavity-nesting birds.

### THE FOREST SNAG INDEX

This index consists of five categories or keywords:

- Snags-general
- Snag management and bird use
- Snag-fire control relationships
- Snag removal and use by man
- Snag longevity

The key word "snags—general" is a summary category. All of the titles relating to snags are listed after this keyword even though they may also be listed after other keywords in this index. The keyword "snag removal and use by man" refers to use of snags by humans for other than wildlife related uses.

### THE FIRE, INSECT, DISEASE, AND DECAY INDEX

The categories or keywords included in this index are:

- Fire effects on cavity-nesting birds
- Insect-cavity-nesting bird relationships
- Nest tree disease and decay

### THE CAVITY-NESTING BIRD INDEX

This index has 88 major divisions. The first division is an index of references that contain general information on cavity-nesting birds. It is not species specific. This index is labeled "cavity-nesting birds – general information" and the keywords are:

- Habitat management
- Land use impacts on habitat
- Habitat
- Foraging behavior
- Breeding, nesting
- Nest and roost trees
- Nests
- Biology, ecology, life history
- Population, densities, distribution, diversity
- Urban-area habitat
- Relation to agriculture
- Damage (by birds)
- Relations with other fauna
- Study methods
- Literature reviews and bibliographies
- Checklists
- Extinct species

The balance of the cavity-nesting bird index consists of separate indexes for each of 86 different cavity-nesting birds known to frequent North American forests. A "woodpeckers—general information" index precedes the indexes for specific woodpeckers. This was necessary to handle the large amount of literature that deals with these birds as a group. Keywords used for the species (and group) specific indexes are:

- Summary
- Habitat management
- Habitat
- Foraging behavior
- Breeding, nesting
- Nest and roost trees
- Nest boxes and houses
- Biology, ecology, life history
- Relations with other fauna
- Territory
- Distribution, population, density, status
- Identification, taxonomy
- Damage

All of the references listed for a given species are summarized following the keyword "summary." Conversely, each reference listed after the keyword "summary" is also listed after one or more of the other keywords used for the bird species.

If one of the keywords is not used for a given species, it is because appropriate references are not included in this bibliography.

The selection and order of the index words is arbitrary. They are purposely biased towards the needs of the forest manager. Birds are listed in the order prescribed by the American Ornithologist's Union.[4]

## The Geographic Index

The Geographic Index is designed to help users find information pertaining to a specific area. Titles are indexed according to country and, for U.S. and Canadian literature, State or Province. U.S. references are also indexed according to section, i.e., Northeast, Southeast, etc. The important thing to remember when using the Geographic Index is that literature is indexed at the most specific level possible and then not included at a broader level. For example, a reference about the eastern bluebird in New York will be listed following the keyword "New York" and **will not** be repeated following the keywords "Northeast," "United States," or "North America."

## How to Use the Bibliography

This bibliography is designed for easy use. The user should become familiar with the indexes and their keywords before starting a search. To make a search, select the appropriate index and keywords and list the reference numbers provided. Use these reference numbers to identify the author, title, and source of the reference in the list of titles and reference numbers.

# FINDING CURRENT LITERATURE

Most of the titles listed in this bibliography were published before 1980. Three of the many sources of information about cavity-nesting birds and related current literature that forest

[4]American Ornithologist's Union. 1957 Check-list of North American Birds. 691 p. Lord Baltimore Press, Baltimore, Md.

managers might find useful because of their easy availability are:

1. **USDA Forest Service**—lists of current research publications. These lists are distributed regularly by the Forest and Range Experiment Stations. To get your name on the mailing list, write to the Station's Director at one of the following addresses:

Intermountain Forest and Range Experiment Station
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1992 Folwell Ave., St. Paul, MN 55108

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370 Reed Rd., Broomall, PA 19008

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809 NE 6th Ave., Box 3141, Portland, OR 97208

Pacific Southwest Forest and Range Experiment Station
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Rocky Mountain Forest and Range Experiment Station
240 W. Prospect St., Fort Collins, CO 80521

Southeastern Forest Experiment Station
Post Office Building, Box 2570, Asheville, NC 28802

Southern Forest Experiment Station
U.S. Postal Service Building, 701 Loyola Ave.,
New Orleans, LA 70113

2. **Wildlife Review**—an indexing and abstracting publication of the Fish and Wildlife Service, U.S. Department of the Interior. For subscription information, write to the Editorial Office, U.S. Fish and Wildlife Service, 270 Ayleworth Hall, Colorado State University, Fort Collins, CO 80523.

3. **Journal of Forestry**—current forestry literature is listed in each issue. The Journal is mailed monthly to members of the Society of American Foresters. For information, write Society of American Foresters, 5400 Grosvenor Lane, Bethesda, MD 20014.

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## South America



## Unclassified as to Geographic Area




United States Regions

Fischer, William C., and B. Riley McClelland.
1983. A cavity-nesting bird bibliography—including related titles on forest snags, fire, insects, disease, and decay. USDA For. Serv. Gen. Tech. Rep. INT-140, 79 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Provides subject matter and geographic keyword indexes to more than 1,700 titles containing information about 86 species of cavity-nesting birds that inhabit North American forests. Related titles containing information about forest snags, fire, insects, disease, and decay are included.

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KEYWORDS: cavity-nesting birds, forest snags, fire effects, insects, disease, decay

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**Intermountain
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Ogden, UT 84401**

General Technical
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May 1983

# Fire Ecology of Montana Forest Habitat Types East of the Continental Divide

**William C. Fischer and Bruce D. Clayton**

CLEMSON UNIVERSITY
AUG 17 1983
DOCUMENTS

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## RESEARCH SUMMARY

This report summarizes available information on fire as an ecological factor for forest habitat types occurring east of the Continental Divide in Montana.

Forest habitat types of Montana are grouped into Fire Groups based primarily on fire's role in forest succession.

For each Fire Group, information is presented on (1) the relationship of major tree species to fire, (2) fire effects on undergrowth, (3) forest fuels, (4) the natural role of fire, (5) fire and forest succession, and (6) fire management considerations.

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# CONTENTS

# Fire Ecology of Montana Forest Habitat Types East of the Continental Divide

**William C. Fischer and Bruce D. Clayton**

## INTRODUCTION

### Purpose

This report is a summary of available fire ecology and management information that applies to forest habitat types occurring east of the Continental Divide in Montana; specifically, on the Beaverhead, Custer, Deerlodge, Gallatin, Helena, and Lewis and Clark National Forests; in the Bearpaw Mountains; the Little Rocky Mountains; and the Missouri River Breaks in Montana. The primary purpose of this report is to help forest managers understand the role of fire in east side Montana forests, especially the role of fire in forest succession. Primary attention is given to the tree component although undergrowth response is summarized.

Habitat types are arranged into 11 "Fire Groups" based on the response of the tree species to fire and the roles these tree species take during successional stages. The exception is Fire Group Zero, which is a description of miscellaneous vegetation types.

The Fire Groups defined in this report include a number of borderline cases. Differences in fire behavior and in successional patterns often depend on very small local changes in fuel, temperature, moisture, sunlight, topography, and seed availability. Thus it would be possible for stands that key to the same habitat type to fall into different Fire Groups. Assignment of habitat types to more than one Fire Group is kept to a minimum in this report. A certain reliance is placed on the judgment of the land manager in evaluating the local conditions of any particular site. The groups defined in this report are intended as a general guide, not a definitive treatment.

Where similar habitat types occur on lands adjoining those covered in this report, the information may be extrapolated with care.

### Format

The report is patterned after *Fire Ecology of Lolo National Forest Habitat Types* (Davis and others 1980). Subject matter content is identical to the Lolo report except that this report contains a discussion of hypothetical successional pathways. A major difference in format is that in this report the relationships of major tree species to fire and fire effects on undergrowth are discussed in separate sections rather than under each Fire Group. The change was made to eliminate unnecessary repetition. Since publication of the Lolo report, downed dead woody fuel and biomass in the Northern Rocky Mountains has been summarized by Brown and See (1981). Consequently, in this report summaries of average downed woody fuel loads for east side forests are included in a preliminary section on forest fuels that precedes the Fire Group discussions.

The following are the major topics to be covered in this report:

#### RELATIONSHIP OF MAJOR TREE SPECIES TO FIRE

This section is devoted to a discussion of each important tree species in east side forests with regard to its resistance or susceptibility to fire and its role as a successional component of forest communities. Particular attention is given to special adaptations to fire, such as corky bark, serotinous cones, or seeds that require mineral soil for germination.

#### UNDERGROWTH RESPONSE TO FIRE

This section is a summary of the effect of fire on the response of important understory grass, forb, and shrub species. Particular attention is given to fire-adaptive traits or survival strategies that determine whether fire generally increases or decreases species cover in the immediate postfire period.

## HABITAT TYPES AND PHASE, ADP CODES AND FOREST REGION

The Fire Groups are defined with reference to *Forest Habitat Types of Montana* (Pfister and others 1977); *Forest Habitat Types of the Bear's Paw Mountains and Little Rocky Mountains, Montana* (Roberts 1980); and *Forest and Woodland Habitat Types of North Central Montana, Volume 2: The Missouri River Breaks* (Roberts and Sibbernsen 1979). A complete list of the habitat types occurring east of the Continental Divide in Montana is included as appendix A.

Habitat types are designated in the standard format of "series/type-phase," in which "series" designates the potential climax dominant tree, "type" designates a definitive undergrowth species, and "phase" provides a further subdivision where needed. The "ADP codes" are the automatic data processing codes for National Forest System use in the Forest Service Northern Region. ADP codes have not been assigned for those habitat types that do not occur on the National Forests.

The forest region designation refers to those described for Montana by Arno (1979) as illustrated in figure 1.

## FOREST FUELS

For each Fire Group, we discuss the kind and amount of dead, woody material likely to be found on the forest floor. The discussion is based on fuel inventory data (Brown 1974) from two sources. The prime source is a photo series for appraising natural fuels in wild stands on Montana National Forests (Fischer 1981a, 1981b). The other source is a summary of downed dead woody fuel on east side National Forests in Montana (Brown and See 1981), which is presented in a separate section preceding the Fire Group discussions.

It is important to remember that these discussions are about dead, woody material on the forest floor. Live fuel and standing dead fuel are treated casually, if at all, because fuel data on this material were not collected as part of the inventories mentioned above.

Cover type names used in this section are those suggested by the Society of American Foresters (1980).

## ROLE OF FIRE

Information on the important trees and forest fuel is integrated with available fire history studies to describe the role of fire in shaping the vegetative composition of a particular Fire Group. This section is mainly a literature review covering succession and fire in the appropriate habitat types.

For the purpose of this report three levels of fire severity are recognized: low or cool, moderate, and high or severe. A **low severity** or **cool fire** is one that has minimal impact on the site. It burns in surface fuels consuming only the litter, herbaceous fuels, and foliage and small twigs on woody undergrowth. Very little heat travels downward through the duff. A **moderate fire** burns in surface fuels also but may involve a tree understory as well. It consumes litter, upper duff, understory plants, and foliage on understory trees. Individual and groups of overstory trees may torch out if fuel ladders exist. A **severe fire** is one that burns through the overstory and consumes large woody surface fuels and/or removes the entire duff layer over much of the area. Heat from the fire impacts the upper soil layer and often consumes the incorporated soil organic matter.

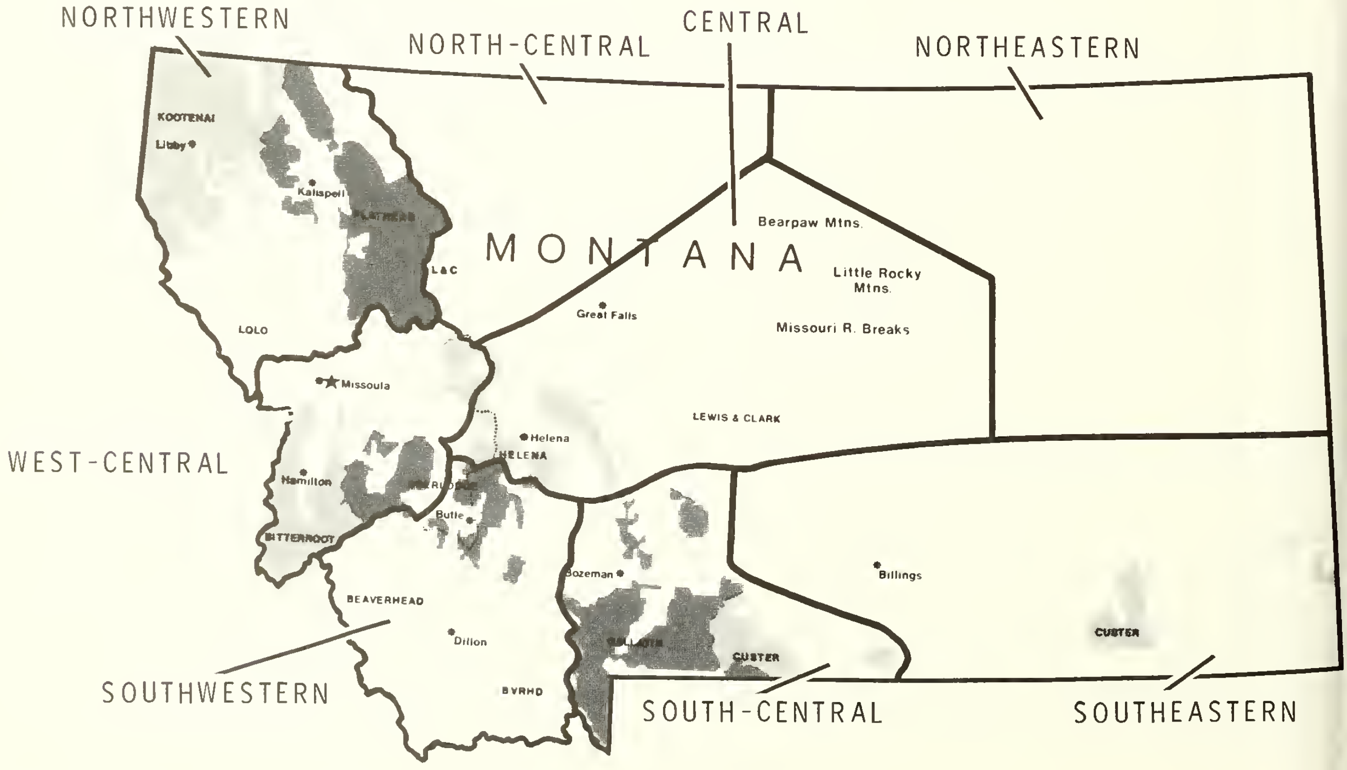



*Figure 1.—Forest regions of Montana (source: Arno 1979).*

## GENERALIZED FOREST SUCCESSION

The succession diagram and associated text represent a simplified, synthetic overview of fire's role in succession for all habitats of each Fire Group. For clarity, no literature references are given in this section since it is intended to serve as a graphic and uncomplicated presentation of the material covered earlier in the chapter.

The diagram in each of these sections represents a visual summary of the effects that fires of varying intensity can have on the habitat types. Secondary succession begins with the lowest seral form, but the diagram can be used from any stage of stand development. In habitat types with aggressive seral conifers, the shrub/herb stage is short lived. Numerous facts that may influence the vegetation on the landscape have been neglected in order to emphasize the potential influences of fire and fire suppression.

The conifer species are symbolized in order to simplify the diagrams. The symbols are defined as follows:

*Abies lasiocarpa*, subalpine fir (ABLA)
*Juniperus scopulorum*, Rocky Mountain juniper (JUSC)
*Larix lyallii*, alpine larch (LALY)
*Picea engelmannii*, Engelmann spruce (PICEA)
*Pinus albicaulis*, whitebark pine (PIAL)
*Pinus contorta*, lodgepole pine (PICO)
*Pinus flexilis*, limber pine (PIFL)
*Pinus ponderosa*, ponderosa pine (PIPO)
*Pseudotsuga menziesii*, Douglas-fir (PSME)

## SUCCESSIONAL PATHWAYS

This section provides a more detailed discussion of potential forest succession than the previous section. It is a synthesis of confirmed knowledge and unconfirmed speculation that forms a complex series of hypotheses about the many possible influences fire may have on the vegetation of the Fire Groups. The flow charts follow the method suggested by Kessell and Fischer (1981).

## FIRE MANAGEMENT CONSIDERATIONS

This section suggests how the preceding information can be used to develop fire management plans that support land and resource management objectives. The discussion is intended to be suggestive, not dogmatic. Each individual manager is in a much better position than are the authors to relate the information presented in this report to a particular management situation.

# The Fire Groups

The forest habitat types of Montana have been assembled into 12 Fire Groups (table 1) that are defined as follows:

**Fire Group Zero**: A miscellaneous, heterogeneous collection of special habitats. On eastern Montana National Forests these sites exist as scree, forested rock, meadow, grassy bald, aspen grove, and alder glade.

**Fire Group One**: Dry limber pine habitat types. These occur almost exclusively east of the Continental Divide in Montana.

**Fire Group Two**: Warm, dry ponderosa pine habitat types. This group consists of open ponderosa pine stands with a predominantly grass undergrowth and dense mixed-aged stands of ponderosa pine. These sites may exist as fire-maintained grasslands, and do not support Douglas-fir, except as "accidental" individuals.

**Fire Group Three**: Warm, moist ponderosa pine habitat types. These sites occur exclusively east of the Continental Divide in Montana. These sites often exist as stagnant, overgrown thickets of ponderosa pine saplings.

**Fire Group Four**: Warm, dry Douglas-fir habitat types. These are areas that exist in nature as fire-maintained ponderosa pine stands that develop Douglas-fir regeneration beneath the pine in the absence of fire.

**Fire Group Five**: Cool, dry Douglas-fir habitat types. Douglas-fir is often the only conifer that occurs on these sites. In the absence of fire, dense Douglas-fir sapling understories may develop.

**Fire Group Six**: Moist Douglas-fir habitat types. These habitat types will support substantial amounts of Douglas-fir even when subjected to periodic fire.

**Fire Group Seven**: Cool habitat types usually dominated by lodgepole pine. This group includes stands in which fire maintains lodgepole pine as a dominant seral as well as those in which it is a persistent dominant species.

**Fire Group Eight**: Dry, lower subalpine habitat types. This is a collection of habitat types in the spruce and subalpine fir series that usually occurs as mixed Douglas-fir/lodgepole pine stands.

**Fire Group Nine**: Moist, lower subalpine habitat types. This is a collection of habitat types in which fires are infrequent but severe, with long-lasting effects. Spruce is usually a major component of seral stands.

**Fire Group Ten**: Cold, moist upper subalpine and timberline habitat types. This is a collection of high-elevation habitats in which fires are infrequent. Fires are small in areal extent because of the fuel situation. Severe fires have long-term effects. Spruce, subalpine fir, whitebark pine, and alpine larch are the predominant conifers.

**Fire Group Eleven**: Moist grand fir, western redcedar, and western hemlock habitat types. These are moist habitats in which fires are infrequent and often severe. In Montana they occur exclusively west of the Continental Divide.

All these except Fire Group Eleven occur on eastern Montana National Forests. Fire Group Eleven, consequently, will not be discussed in this report. A detailed listing of the Fire Groups by habitat type is provided in appendix B.

Table 1.—Summary of Montana forest habitat type fire groups (see Appendix C for formal listing of habitat types).

| Habitat type[1] | Forest region[2] |
|---|---|
| **FIRE GROUP ONE** | |
| PIFL/AGSP | NC, C, SW, SC |
| PIFL/FEID-FEID | NC, C, SW, SC |
| PIFL/FEID-FESC | NC,C |
| PIFL/JUCO | NC, C, SW, SC |
| **FIRE GROUP TWO** | |
| PIPO AND | SE |
| PIPO/AGSP + | NW, WC, C, SE |
| PIPO/FEID-FEID | WC, C, SE |
| PIPO/FEID-FESC + | NE, WC, C |
| PIPO/PUTR-AGSP | WC, C |
| PIPO/PUTR-FEID | NW, WC, C |
| PIPO/SYAL-SYAL | NW, WC, C, SE |
| PIPO/SYOC* | C |
| PIPO/ARUV* | C |
| PIPO/JUHO* | C |
| PIPO/JUSC** | C |
| **FIRE GROUP THREE** | |
| PIPO/SYAL-BERE | C, SE |
| PIPO/BERE* | C |
| PIPO/AMAL* | C |
| PIPO/PRVI-PRVI | SE |
| PIPO/PRVI-SHCA | SE |
| **FIRE GROUP FOUR** | |
| PSME/AGSP | NW, WC, C, SW, SC |
| PSME/FESC | NW, WC, C |
| PSME/PHMA-CARU | NW, WC |
| PSME/SYAL-AGSP | NW, WC, C |
| PSME/SYOC-CHVI* | C |
| PSME/SYOC-SHCA* | C |
| PSME/CARU-AGSP | NW, WC |
| PSME/CARU-PIPO | NW, WC, C |
| PSME/SPBE | NW, WC, C, NC |
| PSME/ARUV + | C, SC |
| PSME/BERE-ARUV* | C |
| PSME/BERE-BERE* | C |
| PSME/JUSC** | C |
| PSME/MUCU** | C |
| **FIRE GROUP FIVE** | |
| PSME/FEID | NW, WC, SW, SC |
| PSME/CARU-AGSP | C |
| PSME/CAGE | WC, C, SC, SW |
| PSME/ARCO | C, SW |
| PSME/SYOR | SW |
| PICEA/SEST-PSME | NC, C, SW |
| **FIRE GROUP SIX** | |
| PSME/PHMA-PHMA | NW, WC, C, SW, SC |
| PSME/VICA* | C |
| PSME/VAGL-VAGL | NW, WC, C, SW, SC |
| PSME/VAGL-ARUV | NW, WC, C |
| PSME/VAGL-XETE | NW, WC, C |
| PSME/LIBO-SYAL | NW, WC, C |
| PSME/LIBO-ARUV* | C |
| PSME/LIBO-CARU + | NW, WC, C, SW |
| PSME/LIBO-VAGL | WC, C |
| PSME/SYAL-CARU | NW, WC, C, SW, SC |
| PSME/SYAL-SYAL | NW, WC, NC, C, SW, SC |
| PSME/AMAL* | C |
| PSME/CARU-ARUV | NW, WC, C |
| PSME/CARU-CARU | NW, WC, NC, C, SW, SC |
| PSME/VACA | NW, WC |
| PSME/JUCO | NC, C, SW |
| **FIRE GROUP SEVEN** | |
| PSME/JUCO | NC, C, SW |
| PSME/VACA | NW, WC, NC, C |
| PSME/COCA-LIBO* | C |
| PSME/COCA-VAMY* | C |
| PICEA/VACA | NW, NC |
| PICEA/LIBO | WC, C, SC, SW |
| ABLA/VACA | NW, WC, C, SW |
| ABLA/CACA-VACA | NW, WC, C, SW |
| ABLA/LIBO-VASC | NW, WC, NC, C, SC, SW |
| ABLA/XETE-VASC | NW, WC, NC, SW |
| ABLA/VAGL | WC, C, SC, SW |
| ABLA/VASC-CARU | C, SC, SW |
| ABLA/VASC-VASC | NW, WC, C, SC, SW |
| ABLA/CAGE-CAGE | NC, SW |
| PICO/PUTR | SC |
| PICO/VACA | WC, NC, C, SW |
| PICO/LIBO + | NW, WC, C, SC, SW |
| PICO/VASC | NW, WC, C, SC, SW |
| PICO/CARU | C, SC, SW |
| PICO/JUCO | C |
| **FIRE GROUP EIGHT** | |
| PICEA/LIBO* | C |
| PICEA/PHMA | SC |
| PICEA/SMST | WC, C, SW, SC |
| ABLA/XETE-VAGL | NW, WC, NC, SW |
| TSME/XETE | NW |
| ABLA/VASC-THOC | C, SW |
| ABLA/CARU | NC, C, SW, SC |
| ABLA/CLPS | NC, C, SW, SC |
| ABLA/ARCO | NC, C, SW |
| ABLA/CAGE-PSME | C, SW, SC |
| **FIRE GROUP NINE** | |
| PICEA/EQAR | NW, NC, C, SW, SC |
| PICEA/CLUN-VACA | NW |
| PICEA/CLUN-CLUN | NW |
| PICEA/GATR | WC, C, SW, SC |
| ABLA/OPHO | NW |
| ABLA/CLUN-CLUN | NW, WC, NC |
| ABLA/CLUN-ARNU | NW, WC, NC |
| ABLA/CLUN-VACA | NW, WC |
| ABLA/CLUN-XETE | NW, WC, NC |
| ABLA/CLUN-MEFE | NW, WC, NC |
| ABLA/GATR | WC, NC, C, SC |
| ABLA/CACA-CACA | WC, C, SW, SC |
| ABLA/CACA-GATR | WC, C, SW |
| AGLA/LIBO* | C |
| ABLA/LIBO-LIBO | NW, WC, NC, C, SW, SC |
| ABLA/LIBO-XETE | NW, WC |
| ABLA/MEFE | NW, WC, NC, SW, SC |
| TSME/MEFE | NW, WC |
| ABLA/ALSI | WC, NC, SW, SC |
| **FIRE GROUP TEN** | |
| PICEA/SEST-PICEA | C |
| PICEA/JUCO* | C |
| ABLA/RIMO | SW, SC |
| ABLA-PIAL/VASC | WC, NC, C, SW, SC |
| ABLA/LUHI-VASC | NW, WC, NC, SW |
| ABLA/JUCO* | C |
| TSME/LUHI-VASC | NW |
| TSME/LUHI-MEFE | NW |
| PIAL—ABLA h.t.s. | NW, WC, NC, C, SW, SC |
| LALY-PIAL h.t.s. | NW, WC, SW |
| PIAL h.t.s. | WC, C, SW, SC |
| **FIRE GROUP ELEVEN** | |
| ABGR/XETE | NW, WC |
| ABGR/CLUN-CLUN | NW, WC |
| ABGR/CLUN-ARNU | NW, WC |
| ABGR/CLUN-XETE | NW |
| ABGR/LIBO-LIBO | NW, WC |
| ABGR/LIBO-XETE | NW |
| THPL/CLUN-CLUN | NW, WC |
| THPL/CLUN-ARNU | NW, WC |
| THPL/CLUN-MEFE | NW, WC |
| THPL/OPHO | NW |
| TSHE/CLUN-CLUN | NW |
| TSHE/CLUN-ARNU | NW |

[1]Habitat types are as described by Pfister and others (1977) except those designated as follows:
*habitat types of Bearpaw and Little Rocky Mountains (Roberts 1980)
**habitat types of Missouri River Breaks (Roberts and Sibbernsen 1979)
+ common to both Pfister and others (1977) and Roberts (1980).
[2]Forest regions are as described by Arno (1979).

## Nomenclature

Trees and undergrowth plants are identified by their common names throughout the text of this report. The list of habitat types at the beginning of each Fire Group discussion reflects the common practice of noting scientific names, abbreviations, and common names. Habitat types are most often identified by abbreviation in the text. Appendix C is a complete list of scientific plant names corresponding to the common plant names used in the text.

# RELATIONSHIP OF MAJOR TREE SPECIES TO FIRE

Wildfire has played a major role in forest succession throughout the Northern Rocky Mountains, including those forests east of the Continental Divide in Montana. Lodgepole pine, for example, owes its present widespread occurrence to past fire. Without fire Douglas-fir would occupy areas where ponderosa pine now occurs but is not climax. Similarly, Douglas-fir occupies many sites where it is not climax because of past fire. Fire has favored the distribution of Engelmann spruce at the expense of subalpine fir (Wellner 1970).

Fire may or may not favor a given species depending on certain physical characteristics of the species and its regeneration strategy. Physical characteristics determine a species' susceptibility or resistance to fire damage, while regeneration strategy determines whether a species' continued presence on a site is enhanced or curtailed by fire.

Table 2 summarizes the relative fire resistance of the more silviculturally important conifers in east side Montana forests. A more complete review and summary of comparative autecological characteristics of northwestern tree species is provided by Minore (1979).

Nine coniferous forest trees are discussed in this report. They are limber pine, ponderosa pine, Rocky Mountain juniper, Douglas-fir, Engelmann spruce (including Engelmann spruce and white spruce hybrids), lodgepole pine, subalpine fir, whitebark pine, and alpine larch. The relationship of each tree species to fire is discussed below. Order of presentation corresponds to the order in which the species are encountered in the Fire Groups.

## Limber Pine (*Pinus flexilis*)

The degree of stem scorch usually determines the extent of fire injury to limber pines. Young trees are usually killed by any fire that scorches their stems. The bark of young limber pine is too thin to prevent cambium injury, even from a cool fire. Older trees are better able to withstand stem scorch from low severity fires because the bark around the base of mature trees is often 2 inches (5 cm) thick. The needles of limber pine form into tight clusters around the terminal buds. This shields the buds from heat associated with crown scorch.

Keown (1977) conducted prescribed fire studies on Group One habitat types in the central forest region of Montana (Lewis and Clark National Forest). The study results indicate a strong relationship between fuel type, fire severity, and fire injury to limber pine. On sites where grass was the primary fuel and where trees were present as scattered individuals or open stands, fire severity was low and limber pine mortality was light (about 20 percent) even though basal limbs commonly extended to the ground. In similar situations but with a dense undergrowth of shrubs (primarily shrubby cinquifoil) rather than a grass understory, fire severity was high and limber pine mortality often reached 80 percent. The final situation reported by Keown (1977) was where a closed canopy forest bordered grassland or shrubland. Trees in these transition zones were often less than 10 ft (3 m) tall with lower branches intermingled with ground fuels. The most severe fires occurred on these sites. These results are from spring fires when temperatures, relative humidities, and winds were moderate, fuel moistures low, and soil moistures high.

There is no evidence to suggest that fire is necessary to prepare seedbeds for limber pine. Many limber pine habitats are characterized by scattered patches of bare soil. Some sites are heavily covered by bunchgrasses. In the Blacktail Hills area of the Lewis and Clark National Forest, limber pine invades sites occupied by grass and shrubs. On the Hogback Ridge area

**Table 2.**—Relative fire resistance of the more silviculturally important conifers occurring east of the Continental Divide in Montana[1] (source: Wellner 1970)

| Species | Thickness of bark of old trees | Root habit | Resin in old bark | Tolerance: Branch habit | Tolerance: Stand habit | Relative inflammability of foliage | Lichen growth | Degree of fire resistance |
|---|---|---|---|---|---|---|---|---|
| Ponderosa pine | Very thick | Deep | Abundant | Moderately high and open | Open | Medium | Medium to light | Very resistant |
| Douglas-fir | Very thick | Deep | Moderate | Moderately low and dense | Moderate to dense | High | Heavy medium | Very resistant |
| Lodgepole pine | Very thin | Deep | Abundant | Moderately high and open | Open | Medium | Light | Medium |
| Engelmann spruce | Thin | Shallow | Moderate | Low and dense | Dense | Medium | Heavy | Low |
| Subalpine fir | Very thin | Shallow | Moderate | Very low and dense | Moderate to dense | High | Medium to heavy | Very low |

[1]From Flint (1925).

of the Helena National Forest (also in the central forest region), limber pine is becoming established in mats of common juniper on a PIFL/JUCO h.t., which last burned more than 60 years ago. Limber pine has large, wingless seeds incapable of wind dispersal. A recent study by Lanner and Vander Wall (1980) indicates that limber pine regeneration on burns is largely a result of seeds planted by Clark's nutcrackers. These birds store limber pine seed in the soil for food. No other reliable dispersal agent of limber pine seed has been identified.

Limber pine occurs primarily in Fire Group One but is also present as a minor species in Fire Groups Six and Eight.

## Ponderosa Pine (*Pinus ponderosa*)

Ponderosa pine has many fire-resistant characteristics. Seedlings and saplings are often able to withstand relatively high temperatures, whether from a light surface fire during dormancy or from the severe thermal stress inherent in becoming established on hot, dry exposures. Development of insulative bark and the tendency for meristems to be shielded by enclosing needles and thick bud scales, contribute to the temperature resistance of pole-sized and larger trees.

Propagation of fire into the crown of pole-sized and larger trees growing in relatively open stands (dry sites) is unusual because of three factors. First, the thick bark is relatively unburnable and does not easily carry fire up the bole or support residual burning. Resin accumulations, however, make the bark more flammable. Second, the tendency of ponderosa pine to self-prune lower branches keeps the foliage separated from burning surface fuels. Third, the open, loosely arranged foliage does not lend itself to combustion or the propagation of flames.

On moist sites, ponderosa pine often forms two-storied stands that may be quite susceptible to crown fire. The tendency for regeneration to form dense understories, or "dog hair" thickets, on such sites creates fuel ladders that can carry ground fires to the crowns of overstory trees. Crown fires are, consequently, more frequent on moist sites than they are on dry sites. Understory ponderosa pine may also be more susceptible to fire damage because crowded conditions can result in slower diameter growth. Such trees do not develop their protective layer of insulative bark as early as would otherwise be expected. They remain vulnerable to cambium damage from ground fires longer than their counterparts in open stands. The thick, overcrowded foliage of young stands or thickets also negates the fire-resisting characteristic of open, discontinuous crown foliage normally found in this species. The thinning effect of fire is therefore much more pronounced in dense stands than it is in open stands.

Ponderosa pine seedling establishment is favored when fire removes the forest floor litter and grass and exposes mineral soil. Fire resistance of the open, parklike stands is enhanced by variable light fuel quanities. Heavy accumulations of litter at the base of trunks increase the intensity and duration of fire, often resulting in a fire scar or "cat face." Flammable resin deposits around wounds can make the tree susceptible to fire damage and usually cause an enlargement of the scar.

Ponderosa pine is the most fire-resistant tree growing east of the Divide in Montana. It has, consequently, a competitive advantage over other species when mixed stands burn.

Ponderosa pine occurs primarily in Fire Groups One, Two, Three, and Four.

## Rocky Mountain Juniper (*Juniperus scopulorum*)

Young juniper trees are easily killed by fire primarily because of their small size, thin bark, and compact crown. Fire has long been recognized as a means to control juniper because it does not resprout. Often young trees are killed just by scorching the crown and stem.

As juniper ages, the bark thickens and the crown develops a bushy, open habit. A hot fire can kill or severely damage such a tree, but the same tree may survive a cool fire. Low, spreading branches can provide a route for fire to enter the crown, thereby increasing the potential for damage. Often large junipers will survive a number of fires (four to six).

The different effects of fire on young and old juniper trees are largely a function of the site. The species commonly occupies dry, subhumid environments that support limited undergrowth. When surface fuels are sparse, fire damage is minimal.

Rocky Mountain juniper occurs primarily in Fire Groups One, Two, Three, and Four.

## Douglas-Fir (*Pseudotsuga menziesii*)

Mature Douglas-fir is a moderately fire-resistant tree; saplings, however, are vulnerable to surface fires because of their thin, photosynthetically active bark, resin blisters, closely spaced flammable needles, and thin twigs and bud scales. The moderately low and dense branching habit of saplings enables surface fires to be carried into the crown layer. Older trees develop a relatively unburnable, thick layer of insulative corky bark that provides protection against cool to moderately severe fires, but this protection is often offset by a tendency to have branches the length of the bole. The development of "gum cracks" in the lower trunk that streak the bark with resin, can provide a mechanism for serious fire injury.

Douglas-fir does occur in open-growth stands, but it also grows in denser stands with continuous fuels underneath. Dense sapling thickets can form an almost continuous layer of flammable foliage about 10 to 26 ft (3 to 8 m) above the ground that will support wind-driven crown fires. Even small thickets of saplings provide a route by which surface fires can reach the crowns of mature trees.

As with ponderosa pine, heavy fuel accumulations at the base of the tree increase the probability of fire injury. Also, resin deposits usually enlarge old scars.

Douglas-fir regeneration is favored by fire, which reduces vegetation cover and exposes mineral soil so shallow taproots of seedlings can take hold. Douglas-fir is, however, better able than its competitors to regenerate on unburned sites.

Douglas-fir occurs in Fire Groups One, Four, Five, Six, Seven, Eight, and Nine.

## Engelmann Spruce (*Picea engelmannii*)

Engelmann spruce—including Engelmann spruce and white spruce (*Picea glauca*) hybrids—readily succumbs to fire. The dead, dry, flammable lower limbs, low-growing canopy, thin bark, and lichen growth in the branches contribute to the species' vulnerablility. The shallow root system is readily subject to injury from fire burning through the duff. Older trees that have deep accumulations of resinous needle litter around their bases are particularly susceptible. Trees that do survive fire are often subjected to successful attack by wood-destroying fungi that easily enter through fire scars. The high susceptibility of spruce to fire damage is mitigated in part by the generally cool and moist habitats where it grows.

Spruce is not an aggressive pioneer. It is a moderate seeder, but seeds are viable over extended periods. Initial establishment and early growth of seedlings may be slow, but usually good when encouraged by shade and abundant moisture. Spruce seedlings will occur as members of a fire-initiated stand with lodgepole. Spruce's shade tolerance allows it to establish and grow beneath a lodgepole pine canopy. On sites where it is the indicated climax species, spruce will eventually dominate the stand, but it takes a long period without any fire before this situation can occur.

Restocking will occur more quickly if some spruce trees survive within the burn than if regeneration is dependent on seed from trees at the fire edge. Pockets of spruce regeneration often become established around such surviving seed trees up to a distance of 300 ft (90 m), the effective seeding distance for spruce. Successful regeneration diminishes 100 to 150 years after establishment due to insufficient sunlight at ground level and to accumulating duff. At this point, the more tolerant subalpine fir begins to successfully regenerate.

Engelmann spruce occurs primarily in Fire Groups Five, Seven, Eight, Nine, and Ten.

## Lodgepole Pine (*Pinus contorta*)

Individual mature lodgepole pine trees are moderately resistant to surface fires. Lodgepole's thin bark makes it susceptible to death from cambium heating. Lodgepole pine stands alone, however, in its ability to perpetuate itself on a site despite fire. Indeed, on most sites where lodgepole grows, fire is necessary for the species continued dominance.

Lodgepole pine's key fire survival attribute is cone serotiny. Although there are exceptions, most lodgepole stands in eastern Montana are composed of trees containing both serotinous and nonserotinous or open cones. The ratio of serotinous to nonserotinous cones seems to be related to the fire frequency for the site: the higher the fire frequency the greater the proportion of serotinous cones and vice versa (Perry and Lotan 1979).

A temperature of 113° F (45° C) is usually required to melt the resin that binds the scales of a serotinous cone. Heat from a fire is about the only way such temperatures will occur in the crown of a standing lodgepole pine. Large quantities of highly viable seed are therefore available to regenerate a site following a stand-destroying fire.

Aside from serotinous cones, other silvical characteristics (USDA Forest Service 1965) that contribute to lodgepole pine's success in dominating a site following fire are:

1. **Early seed production**. Cones bearing viable seed are produced by trees as young as 5 years in open stands and by trees 15 to 20 years old in more heavily stocked stands. This feature not only allows relatively young stands to regenerate a site following fire, but also the seed from open cones can fill in voids left by the orginal postfire seeding from serotinous cones.
2. **Prolific seed production.** Good cone crops occur at 1- to 3-year intervals with light crops intervening.
3. **High seed viability**. Seed in 80-year-old serotinous cones, for example, have been found to be viable.
4. High seedling survival and rapid early growth, especially on mineral soil seedbeds exposed to full sunlight.

Lodgepole pines' success in revegetating a site following fire often results in dense, overstocked stands. Such stands are susceptible to stagnation, snow breakage, windthrow, dwarf mistletoe (*Arceuthobium americanum*) infestation, and mountain pine beetle (*Dendroctonus ponderosae*) attack. The combined effect of these factors is extreme buildup of downed, dead woody fuel on the forest floor. Thus, the stage is set for another stand-destroying wildfire.

Lodgepole pine occurs primarily in Fire Groups Six, Seven, Eight, and Nine.

## Subalpine Fir (*Abies lasiocarpa*)

Subalpine fir is rated as the least fire-resistant Northern Rocky Mountain conifer because of its thin bark, resin blisters, low and dense branching habit, and moderate-to-high stand density in mature forests. As a result, fire most often acts as a stand-replacement agent when it burns through a subalpine fir forest. Even light ground fires can cook the cambium or spread into the ground-hugging branches and from there up into the crown.

Subalpine fir may begin producing cones when only 20 years old, but maximum seed production is by dominant trees 150 to 200 years old. Subalpine fir has the ability to germinate and survive on a fairly wide range of seedbeds.

Subalpine fir can occur in a fire-initiated stand with Douglas-fir, lodgepole pine, and other seral species because it germinates successfully on a fire-prepared seedbed. Subalpine fir is usually, however, a slower growing minor component, and is usually not as conspicuous as the less tolerant species.

In a closed canopy situation, establishment and early survival of fir are not hampered by deep shade. Subalpine fir can exist under low light conditions better than most associated species. Engelmann spruce will, however, often grow faster than subalpine fir where light intensity exceeds more than 50 percent of full sunlight. Subalpine fir is shade tolerant and is the indicated climax species on many sites containing lodgepole pine. Where a seed source exists, the fir will, consequently, invade and grow in the understory of lodgepole stands. Given a long enough fire-free period, subalpine fir will take over from lodgepole pine on sites where it is the indicated climax.

Subalpine fir occurs in Fire Groups Seven, Eight, Nine, and Ten.

## Whitebark Pine (*Pinus albicaulis*)

Whitebark pine is a semitolerant or midtolerant seral species (Arno and Hoff 1981) that has been observed as a pioneer inhabiting burn sites. It is moderately fire resistant. Whitebark pine has a relatively thin bark and is susceptible to fire injury from hot surface fires that heat the cambium. Its dry, exposed habitat and open structure tend to reduce its vulnerability. The fact that whitebark pine often reaches ages of 500 years or more reflects the reduced fire threat.

Whitebark pine may occur as small groups of trees especially near its lower elevational limit where it appears with subalpine fir and Engelmann spruce. The general impression of whitebark pine habitat types, however, is that of open stands where the undergrowth is predominantly continuous low shrubs, forbs, and grasses. Occasionally larger shrubs and stunted trees occur.

Fires that burn in the undergrowth are usually of low-to-moderate severity. The low, ground-hugging crowns of associated conifers can provide a fuel ladder, and the downfall in the vicinity of mature trees locally increases crown fire potential; hence, severe fires are possible.

Severe wildfires starting in lower elevations can spread throughout the upper elevation forests to timberline. Although the open nature of a whitebark pine forest acts as a firebreak, many trees can be killed under these conditions. The most common fires are lightning fires that do not spread far nor do much damage.

Whitebark pine has a large, wingless seed that does not disperse by wind. Regeneration on burned sites is usually the result of seed germination from Clark's nutcracker and rodent seed caches.

Whitebark pine occurs in Fire Groups Six, Eight, Nine, and Ten.

### Alpine Larch (*Larix lyallii*)

Alpine larch is a thin-barked species easily damaged by fire. However, it is moderately fire-resistant primarily because of its stand habit. It grows only on the highest elevations inhabiting rock faces, talus slopes, shallow soils, and moist, marshy sites. Alpine larch can grow in pure groves, in small groups, or as isolated individuals. In the lower portion of its elevational distribution, it occurs with subalpine fir, Engelmann spruce, and whitebark pine.

In the timberline zone, fire is a cause of tree mortality, but is less frequent and widespread than in contiguous forests below. Severe fires may enter the alpine larch stands from lower forests; however, they do not always adversely affect alpine larch stands. For example, the severe Sundance Fire of 1967 swept the ridges of Roman Nose Mountain burning most of the whitebark pine and killing much of the spruce and fir in the cirques, but caused only minor damage to isolated stands of alpine larch (Arno 1970). Sparse vegetation and rocky slopes curtail the intensity of fire in these areas.

When alpine larch grows in association with a vigorous stand of supalpine fir, Engelmann spruce, and whitebark pine, it is an intolerant seral species that dies out when overtopped by other conifers. Arno (1970) stated that fire allowed alpine larch to remain a major forest component with these species in some areas.

Alpine larch occurs only in Fire Group Ten.

## UNDERGROWTH RESPONSE TO FIRE

Many of the common shrubs and herbaceous plants that grow on the forest floor of Montana forests can renew themselves from surviving plant parts following fire. Some plants are quite susceptible to fire kill and often must reestablish from off-site seed or invasion from unburned patches within or immediately adjacent to the burned area.

Table 3 is a summary of existing knowledge of plant response to fire for some species that occur in east side Montana forests. The fire response information is generalized. Plant response to fire depends on many factors including soil and duff moisture, physiological stage of the plant, and the severity of the fire, especially in terms of the amount of heat that travels downward through the duff and upper layer of soil.

Our primary concern in this report is with tree response to fire. Undergrowth response is, consequently, treated lightly in the Fire Group discussions that follow.

Table 3.—**Summary of postfire survival strategy and fire response information for some shrubs and herbaceous plants occurring in forest east of the Continental Divide in Montana (source: Daubenmire and Daubenmire 1968; Lotan and others 1981; Lyon and Stickney 1976; McLean 1969; Miller 1977; Mueggler 1965; Stickney 1981; Volland and Dell 1981; Wright 1980, 1978, 1972, Wright and Bailey 1980; Wright and others 1979).**

| Species | Fire Group(s) | Postfire survival strategy | Comments on fire response |
|---|---|---|---|
| SHRUBS: | | | |
| *Alnus sinuata*<br>Sitka alder | 9 | Sprouts from surviving root crown. | Usually increases on site following fire. Early seed production (after 5 years) aids in this increase. |
| *Amelanchier alnifolia*<br>Serviceberry | 3, 4, 6 | Sprouts from surviving root crown. | Pioneer species usually survives even severe fires especially if soil is moist at time of fire. Coverage usually increases following fire. |
| *Arctostaphylos uva-ursi*<br>Kinnikinnick | 2, 4, 6, 7, 9 | Sprouts from surviving root crown which is located below soil surface. Fibrous roots and stolons (runners) at soil surface. | Susceptible to fire-kill. Will survive some low severity fires when duff is moist and therefore not consumed by fire. May invade burned area from unburned patches. |
| *Artemesia tridentata*<br>Big sagebrush | 5 | Wind dispersed seed | Very susceptible to fire-kill. Recovery is hastened when a good seed crop exists before burning. |
| *Berberis repens*<br>Oregon grape | 3, 4, 7, 8 | Sprouts from surviving rhizomes which grow 0.5 to 2 in (1.5 to 5 cm) below soil surface. | Moderately resistant to fire-kill. Usually survive all but severe fires that remove duff and cause extended heating of upper soil. |

*(con.)*

Table 3.—Continued

| Species | Fire group(s) | Postfire survival strategy | Comments on fire response |
|---|---|---|---|
| *Cornus canadensis* Bunchberry dogwood | 9 | Sprouts from surviving rhizomes which grow 2 to 5 in (5 to 13 cm) below soil surface. | Moderately resistant to fire-kill. Will survive all but severe fires that remove duff and cause extended heating of upper soil. |
| *Cornus stolonifera* Redosier dogwood | 9 | Sprouts from surviving rhizomes or stolons (runners). | Susceptible to fire-kill. Will often invade burned area from adjacent unburned area or unburned patches. usually a slight increase following most fires. |
| *Holodiscus discolor* Oceanspray | 6 | Sprouts from surviving root crown. | Moderately resistant to fire-kill. Is often enhanced by fire. |
| *Juniperus communis* Common juniper | 1, 4, 5, 6, 7, 8, 10 | Bird dispersed seed. | Very susceptible to fire-kill. Seed requires long germination period. |
| *Juniperus horizontalis* Creeping juniper | 1, 2 | Similar to *J. communis*. | See *J. communis* |
| *Linnaea borealis* Twinflower | 6, 7, 8, 9 | Sprouts from surviving root crown located just below soil surface. Fibrous roots and stolons (runners) at soil surface. | Susceptible to fire-kill. May survive some cool fires where duff is moist and not consumed. Can invade burned area from unburned patches. |
| *Lonicera utahensis* Utah honeysuckle | 9 | Sprouts from surviving root crown. | Often a reduction in cover and frequency following fire. |
| *Menziesia ferruginea* Rusty menziesia | 9, 10 | Sprouts from surviving root crown. | Susceptible to fire-kill. Moderate to severe fires reduce survival and slow redevelopment. |
| *Pachistima myrsinites* Mountain lover | 8 | Sprouts from surviving root crown and from buds along taproot. | Moderately resistant to fire-kill. Usually survives low to moderate severity fires that do not consume the duff and heat soil excessively. Usually increases. |
| *Physocarpus malvaceus* Ninebark | 6, 8 | Sprouts from surviving root crown. | Susceptible to fire-kill. Shallow roots may be damaged by moderate to severe fires. Often a slight decrease following fire. |
| *Potentilla fruticosa* Shrubby cinquefoil | 1 | | Susceptible to fire-kill |
| *Prunus virginiana* Chokecherry | 3, 4 | Sprouts from surviving root crown. | Usually increases coverage following fire. |
| *Purshia tridentata* Antelope bitterbrush | 2, 4, 7 | A weak sprouter. Animal-dispersed seed and seed caches present on area prior to fire. | Very susceptible to fire-kill, especially in summer and fall. Decumbent growth form sprouts vigorously, columnar form does not. Spring burns enhance sprouting, fall burns are best for regeneration by seed. |
| *Ribes lacustre* Prickly currant | 9 | Sprouts from surviving root crown which is located beneath soil surface, and from surviving rhizomes. | Resistant to fire-kill. Usually increase even after a severe fire. |
| *Shepherdia canadensis* Russet buffaloberry | 3, 4, 5, 7, 8, 9 | Sprouts from surviving root crown and from buds along taproot. | Moderately resistant to fire-kill. Will usually survive cool to moderately severe fires that fail to consume duff and heat soil extensively. |
| *Spiraea betulifolia* White spiraea | 3, 4, 5, 6, 7, 8 | Sprouts from surviving root crown and from rhizomes which grow 2 to 5 in (5 to 13 cm) below surface. | Resistant to fire-kill. Will usually survive even a severe fire. Generally increases coverage following fire. |

*(con.)*

Table 3.—Continued

| Species | Fire group(s) | Postfire survival strategy | Comments on fire response |
|---|---|---|---|
| *Symphoricarpos albus* Common snowberry | 2, 3, 4, 6, 7, 8, 9 | Sprouts vigorously from surviving rhizomes which are located between 2 and 5 in (5 and 13 cm) below soil surface. | Resistant to fire-kill. Will usually survive even severe fires. Greatly enhanced by cool to moderately severe fires. |
| *Symphoricarpos occidentalis* Western snowberry | 2, 4 | | Increases coverage after spring burning. |
| *Symphoricarpos oreophilus* Mountain snowberry | 5 | Weak sprouter from surviving root crown. | Moderately resistant to fire-kill. Usually maintains prefire frequency and coverage. |
| *Vaccinium scoparium* Grouse whortleberry | 6, 7, 8, 9, 10 | Sprouts from surviving rhizomes which grow in duff layer or at surface of soil. | Moderately resistant to fire-kill. Will usually survive cool to moderately severe fires that fail to consume the lower layer of duff. |
| FORBS: | | | |
| *Apocynum androsaemifolium* Spreading dogbane | 4 | Sprouts from surviving rhizomes. | Generally maintains prefire frequency following fires. |
| *Aralia nudicaulis* Wild sarsaparilla | 9 | Sprouts from surviving rhizomes. | |
| *Arnica cordifolia* Heartleaf arnica | 5, 6, 7, 8 | Sprouts from surviving rhizomes which creep laterally from 0.4 to 0.8 in (1 to 2 cm) below soil surface. Wind dispersed seed. | Susceptible to fire-kill. Shoots produce small crowns within the duff which are easily killed by all but cool fires which occur when duff is moist. May rapidly invade burned area via windborne seed. |
| *Arnica latifolia* Broadleaf or mountain Arnica | 6, 7, 8, 9, 10 | Sprouts from surviving rhizomes which creep laterally in the soil. | Susceptible to fire-kill. Will usually survive cool to moderately severe fires. May exhibit rapid initial regrowth accompanied by heavy flowering and seedling establishment. |
| *Aster conspicuus* Showy aster | 8 | Sprouts from surviving rhizomes which mostly grow from 0.5 to 2 in (1.5 to 5 cm) below soil surface. | Moderately resistant to fire-kill. Will usually survive cool to moderately severe fires that do not result in excessive soil heating. May rapidly increase following fire. |
| *Astragalus miser* Timber milkvetch | 5, 8 | Sprouts from buds along surviving taproot which may be 2 to 8 in (5 to 20 cm) below the root crown. | Resistant to fire-kill. Can regenerate from taproot even when entire plant crown is destroyed. Can send up shoots and set seed the first year. May increase dramatically following fire. Note: Milkvetch is poisonous to sheep and cattle. |
| *Balsamorhiza sagittata* Arrowleaf balsamroot | 4, 5 | Regrowth from surviving thick caudex. | Resistant to fire-kill. Will survive even the most severe fire. |
| *Clintonia uniflora* Queencup beadlily | 9 | Sprouts from surviving rhizomes. | Usually decreases following fire. Postfire environment evidently not conducive to rapid recovery. |
| *Fragaria virginianas* Wild strawberry | 5, 8 | Sprouts from surviving stolons (runners) at or just below soil surface. | Susceptible to fire-kill. Will often survive cool fires that do not consume duff because of high duff moisture content. |
| *Galium triflorum* Sweetscented bedstraw | 8, 9 | Sprouts from surviving rhizomes. | Susceptible to fire-kill. Usually a sharp decrease following severe fire. Can increase following spring and fall fires. |
| *Pyrola secunda* sidebells pyrola | 5, 6, 8 | Sprouts from surviving rhizomes which grow mostly in the duff or at soil surface. | Susceptible to fire-kill. Coverage frequently reduced following fire. May survive cool fires when duff moisture is high. |

*(con.)*

Table 3.—Continued

| Species | Fire group(s) | Postfire survival strategy | Comments on fire response |
|---|---|---|---|
| *Smilacema racemosa* Feather or false Solomon's seal | 8 | Sprouts from surviving stout creeping rhizomes. | Moderately resistant to fire-kill. May be killed by severe fires that remove duff and heat soil excessively. Usually maintains prefire frequency. |
| *Smilacema stellata* Starry Solomon's seal | 6, 8 | Sprouts from surviving creeping rhizomes. | Moderately resistant to fire-kill. May be killed by fires that remove duff and heat upper soil. Frequency often reduced following fire. |
| *Thalictrum occidentale* Western meadowrue | 5, 6, 7, 8 | Sprouts from surviving rhizomes. | Susceptible to fire-kill. Frequency usually reduced following fire. May survive cool fires that do not consume duff. |
| *Xerophyllum tenax* Beargrass | 6, 7, 8, 9, 10 | Sprouts from a surviving stout surface rhizome. | Susceptible to fire-kill. Will survive cool fires that do not consume duff. Sprouts will flower vigorously after a fire until new overstory canopy develops. |
| *Zigadenus elegans* Death camas | 8 | Sprouts from surviving tunicated bulb. | Resistant to fire-kill. |
| **GRASSES:** | | | |
| *Agropyron spicatum* Bluebunch wheatgrass | 1, 2, 4, 5 | Seed germination and some sprouts from surviving rhizomes. | Usually not seriously damaged by fire. Response depends on severity of fire and physiological state of plant. Damage will be greatest following dry year. |
| *Calamagrostis rubescens* Pinegrass | 4, 5, 6, 7, 8 | Sprouts from surviving rhizomes which grow within the top 2 in (5 cm) of soil. | Moderately resistant to fire-kill. Will usually survive cool to moderately severe fires that do not completely consume duff. Burned areas are often successfully invaded by pinegrass. |
| *Carex geyeri* Elk sedge | 5, 7, 8 | Sprouts from surviving rhizomes. | Invades burned areas and forms dense stands. Often increases following fire. |
| *Carex rossi* Ross sedge | 10 | Seed stored in duff or soil which germinates when heat treated. Sprouts from surviving rhizomes. | Increased coverage usually results following most fires severe enough to heat but not completely consume duff. Often increases. |
| *Festuca idahoensis* Idaho fescue | 1, 2, 4, 5, 10 | Seed germination and survival of residual plant. | Susceptible to fire-kill. Response will vary with severity of fire and phsiological state of plant. Can be seriously harmed by hot summer and fall fires. Only slightly damaged during spring or fall when soil moisture is high. |
| *Festuca scabrella* Rough fescue | 1, 2, 4, 5 | Seed germination and residual plant survival. | Usually harmed by spring burning. |
| *Koeleria cristata* Junegrass | 4 | Seed germination and residual plant survival. | Susceptible to fire-kill. Response will vary according to fire severity and physiological state of plant. |
| *Luzula hitchcockii* Smooth woodrush | 10 | Sprouts from surviving rhizomes. | Often a slight increase following fire. |

## SUMMARY ON DOWNED, DEAD FUEL

Downed, dead woody fuel consists of dead twigs, branches, stems, and boles of trees and shrubs that have fallen and lie on or near the ground (Brown and See 1981). Table 4 is a summary of such fuel for east side forests based on inventories conducted by the Forest Service's Northern Region over 6 years on the Deerlodge, Gallatin, and Helena National Forests.

The values in table 4 are group averages. Habitat type averages are shown in figure 2, which also shows how habitat type loadings compare. Brown and See (1981) provide additional summaries of east side fuel loads that should be useful aids for fire management.

**Table 4.**—Average downed woody loadings and duff depths for east side forests by fire groups (source: Brown and See 1981)

| Habitat type groups[1] | Equivalent fire groups | Downed woody | | | Duff depth |
|---|---|---|---|---|---|
| | | Small | Large | Total | |
| | | *Tons/acre* | | | *Inches* |
| 1 | 1 & 2 | 2.3 | 8.5 | 10.8 | 1.1 |
| 2 | 3, 4, & 5 | 2.5 | 10.5 | 13.0 | 1.0 |
| 3 | 6 | 2.1 | 11.3 | 13.4 | 0.9 |
| 4 | 7 & 8 | 2.4 | 17.0 | 19.4 | 1.2 |
| 5 | 9 | 1.9 | 16.9 | 18.8 | 1.0 |
| 6 | 10 | 2.1 | 9.4 | 11.5 | 0.7 |

1 = Limber pine; ponderosa pine and Douglas-fir/bunchgrass types.
2 = Dry site Douglas-fir and moist site ponderosa pine.
3 = Moist site Douglas-fir.
4 = Cool sites dominated by lodgepole pine; dry, lower elevation subalpine fir.
5 = Moist site, lower elevation subalpine fir.
6 = Cold, moist site upper elevation subalpine fir.

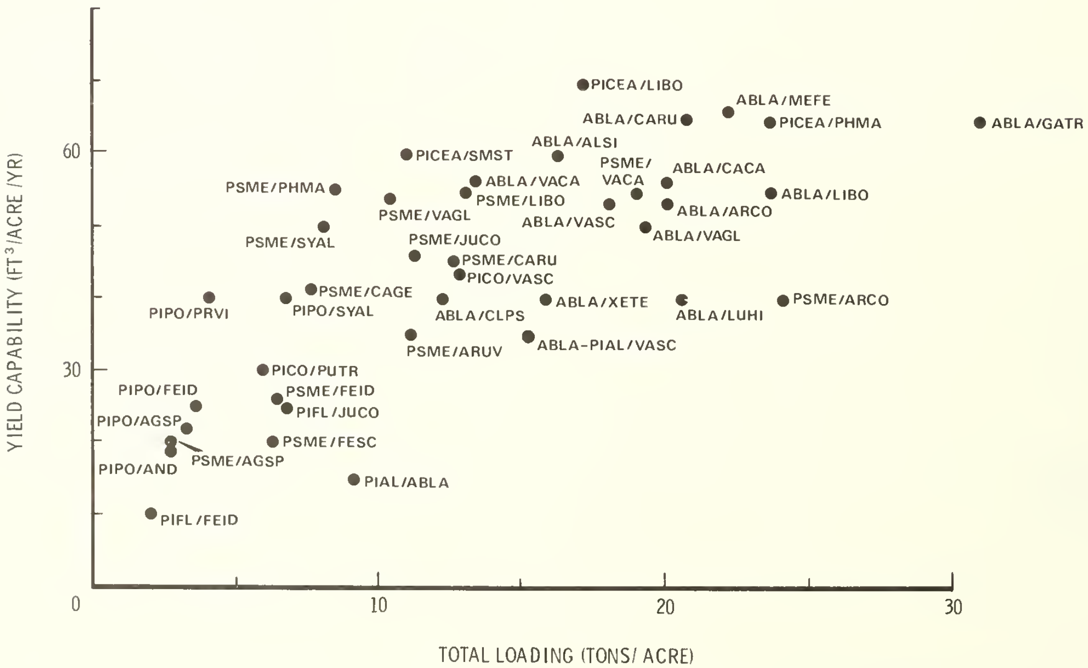



*Figure 2.—Ordination of habitat types by yield capability and total downed woody fuel loading for eastside forests. Yield capabilities are from Pfister and others (1977). (Source: Brown and See 1981.) See table 1 for fire group assignment of habitat types.*

## FIRE GROUP ZERO: MISCELLANEOUS SPECIAL HABITATS

Group Zero is a miscellaneous collection of habitats that have fire ecology and management implications, but that do not fit into the Montana habitat type classifications.

### Scree

The term "scree" refers to slopes covered with loose rock fragments, usually lying almost exactly at the maximum possible angle of repose so that any disturbance causes miniature rock slides down the face of the slope. Scree slopes may be treeless or they may support scattered trees with sparce undergrowth (fig. 3). Usually scree communities are regarded as special environments where the vegetation is in an uneasy equilibrium with the shifting substrate.

In these sites the top layer of talus is moving downhill gradually and is forcing the deep-rooted trees to tilt in the downhill direction. Since the trees continually strive to grow upward, their trunks may become bowed at the base. Surface instability and xeric site conditions at the surface combine to make climax vegetation rare on scree slopes.

The trees most often associated with scree at lower elevations are ponderosa pine, limber pine, Rocky Mountain juniper, and Douglas-fir. At higher elevations, where scree is a major component, these habitats are occupied by lodgepole pine, Engelmann spruce, subalpine fir, or whitebark pine.

The lack of continuous fuel, or of fuel of any kind, often makes scree slopes unburnable. Individual trees or islands of vegetation may ignite, but fire spread is limited. A wind-driven holocaust fire could pass over the intervening open spaces and destroy a scree community, but this rarely happens. Due to the harsh environment, these sites do not revegetate well, and revegetation following a fire can take a very long time.

*Figure 3.—Scree and forested rock are habitats where the influence of fire is minimal (Storm Lake, Deerlodge National Forest). (Bruce Clayton photo.)*

### Forested Rock

Forested rock is usually a very steep canyon wall or mountain side composed of rock outcrops, cliffs, and occasional clumps of trees clinging to ledges and crevices. Forested rock is especially prominent along the canyons of major rivers and in rugged upper subalpine areas near timberline. These sites bear a certain similarity to scree sites, but the substrate is solid and climax species frequently become established.

Surface fires do not burn well because of the vertical and horizontal discontinuity of ground fuels. The probability of crown fires depends on the density and arrangement of trees on the rock face. In some cases the islands of vegetation are so widely scattered as to be almost immune to wildfire. In other cases, particularly low elevation Douglas-fir forested rock communities, a continuity of foliage from the base to the top of a cliff can occur. Each tree forms a ladder into the lower branches of the next higher tree upslope. In such cases crown fires can occur over ground that would not support a less severe surface fire.

Revegetation of rocky sites proceeds at a rate characteristic of the site and depends on the severity of the fire, the age and depth of the soil on ledges and in pockets of rock, erosion if any, and the availability of seeds.

### Meadow

A meadow is an opening in the forest that is characterized by herbaceous vegetation and abundant water. Subirrigation is common during at least some part of the growing season. Mountain meadows are frequently too wet to burn during the fire season. Meadows sometimes act as natural firebreaks, but may carry grass fires during the driest part of the summer and fall.

It is the nature of streamside meadows to gradually become drier in the course of primary succession from the hydric to the mesic condition. The buildup of organic material and trapped sediments from the flowing water, combined with a possible deepening of the streambed and lowering of the water table, can leave former meadows in an intermediate condition between true meadow and grassland. In some such sites the meadow becomes bordered by fire-maintained grassland. Fire suppression has allowed conifers to invade these sites where they would not normally be found.

### Grassy Bald

A grassy bald is a grass-covered opening within an otherwise continuous coniferous forest. Balds may act as firebreaks and can be maintained as grassland by light fires, but usually their fire ecology is less obvious. Billings and Mark (1957) theorize that balds are caused by severe fires that kill all the trees in a stand that happens to lie at the ecotonal limits of a tree species. Following the fire, according to this theory, the new environment is too severe to permit regeneration except under rare circumstances. Reforestation of the area may then be delayed, and evidence of the preceding forest eventually is lost. It is also possible that grassy balds are natural grasslands that have little potential for forest development. Balds may also reflect differences in underlying geologic structures that influence soil moisture retention. Caution is indicated in management of stands adjacent to grassy balds until conditions perpetuating the local balds are determined.

## Aspen Grove

Groves of quaking aspen or quaking aspen and black cottonwood can occur as local climax vegetation on streamside sites or as fire-maintained stands in areas that would otherwise be dominated by conifers. In the fire-maintained areas, the absence of fire can result in the gradual elimination of aspen due to lack of successful regeneration.

## Alder Glade

An alder glade is an opening in the forest occupied by alder. Such sites usually appear on local areas that are too wet for associated conifers. Because they are wet, alder glades burn infrequently, but they also burn very intensely and then resprout from surviving underground stems. Burning tends to make the stand more dense because each burned plant puts up several new shoots during recovery. Alder, like aspen, can exist as a fire-maintained stand in areas where conifer invasion is possible.

## Fire Management Considerations

Group Zero habitats will not burn readily under normal summertime weather conditions. Fire managers can take advantage of this fact when developing preattack plans and when delineating fire management areas, units, or zones. These areas can also serve as anchor points for fuel breaks and firebreaks.

Meadows and aspen groves can be important wildlife habitats. Prescribed fire is a suitable tool for maintaining desired forage conditions in these habitats.

# FIRE GROUP ONE: DRY LIMBER PINE HABITAT TYPES

| **ADP code** | **Habitat type-phase** (Pfister and others 1977) | **Montana forest region** (Arno 1979) |
|---|---|---|
| 040 | *Pinus flexilis/Agropyron spicatum* h.t. (PIFL/AGSP), limber pine/bluebunch wheatgrass. | North-central, central, southwestern, and south-central. |
| 051 | *Pinus flexilis/Festuca idahoensis* h.t.-*Festuca idahoensis* phase (PIFL/FEID-FEID), limber pine/Idaho fescue-Idaho fescue phase. | North-central, central, southwestern, and south-central. |
| 052 | *Pinus flexilis/Festuca idahoensis* h.t.-*Festuca scabrella* phase (PIFL/FEID-FESC), limber pine/Idaho fescue-rough fescue phase. | North-central and central. |
| 070 | *Pinus flexilis/Juniperus communis* h.t. (PIFL/JUCO), limber pine/common juniper. | North-central, central, southwestern and south-central. |

Group One habitat types occupy some of the driest sites capable of supporting trees. Stands are dominated by limber pine, which is often the only tree present. Douglas-fir may occur as a codominant or subordinate species in some stands. Where it does occur on Group One sites, Douglas-fir is often slow growing and of short stature (stunted). These characteristics make it more susceptible to fire damage than it is on most other sites. Ponderosa pine and Rocky Mountain juniper may occur as minor stand components in some areas. Rarely, whitebark pine is a minor climax associate in higher elevation stands. Lodgepole pine and spruce may occur as accidentals.

Group One stands occur below the forest proper as woodlands that extend from the foothills to the adjacent Great Plains (fig. 4A). They also occur on steep, dry, rocky mountain slopes at lower to midelevations (fig. 4B). Trees occupying Group One habitats are usually stunted. Mature trees often are only 20 ft (6 m) and rarely more than 50 ft (15 m) tall.

Bluebunch wheatgrass dominates the undergrowth in lower elevation stands on dry rocky sites. With increasing moisture, Idaho fescue or rough fescue dominate the undergrowth. At the highest elevations occupied by Group One habitat types, the undergrowth is dominated by common juniper, creeping juniper, and dry-site forbs.

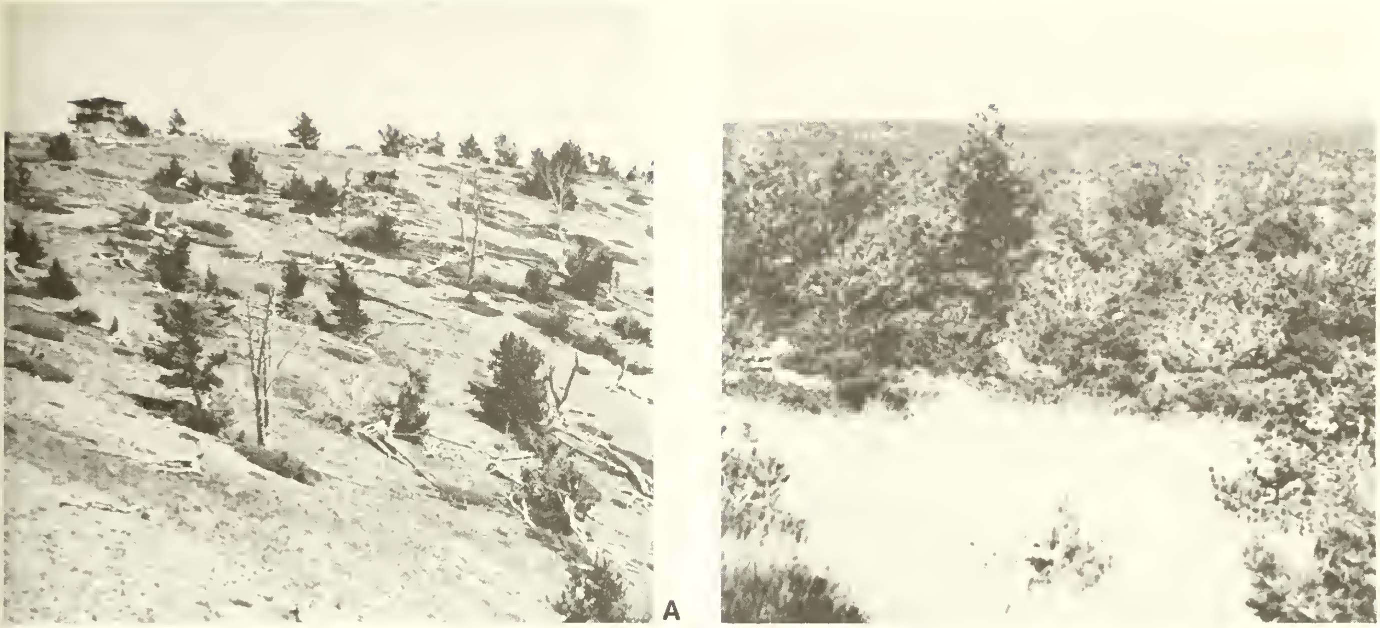
## Forest Fuels

Downed, dead, woody fuel loads range between 5 tons/acre (1 kg/m$^2$) and 15 tons/acre (3.4 kg/m$^2$) in Group One stands. These values are consistent with those calculated by Brown and See (1981) for these habitats (table 4 and fig. 2). About 80 percent or more of the downed woody fuel is usually 3 inches (7.6 cm) in diameter or larger, regardless of the total load. This material is often the result of the falling of snags created by a previous fire. Downed, dead, woody fuels rarely create a serious fire hazard in this group because loadings are usually light and the material is usually scattered about the site (fig. 4). Where hazardous fuel conditions exist, they are often the result of dead herbaceous fuels.

## Role of Fire

Reported fire frequencies for Fire Group One habitats are low. The meager existing evidence suggests that fires hot enough to scar trees occurred 50 to 100 years apart. Arno and Gruell (1983) investigated a PIFL/AGSP stand in southwestern Montana that showed evidence of five fires, the earliest in 1588 and the latest in 1877, for a mean fire interval of 74 years. Pfister and others (1977) sampled 100- to 200-year-old stands in which there was no apparent sign of fire. The available information does not consistantly differentiate between the more severe sites where fuels are light and discontinuous, and the more productive sites where more frequent fire might be expected. Keown's (1977) study was, however, on a productive site, and he reported a fire frequency of 100 years.

Limber pine invasion of adjacent seral grass and shrublands is a slow process because these sites are so dry. The fire susceptibility of young limber pine and Douglas-fir would seem to preclude successful invasion of sites that experience normal grassland fire frequencies of 5 to 25 years (see Fire Groups Two



A B

*Figure 4.—Examples of two limber pine forests in eastern Montana. (A) A woodland type forest on a limber pine/Idaho fescue h.t.-rough fescue phase at the western edge of the Great Plains, northwest of Choteau in central Montana. Trees are a mixture of limber pine and stunted Douglas-fir. (B) A limber pine/common juniper h.t. near the Hogback Lookout, Helena National Forest. A fire swept this ridge 60 or more years ago. The resulting grass and herb undergrowth is slowly being filled in by mats of common juniper and occasional limber pines that may have been planted by Clark's nutcrackers. The standing and down snags indicate the former density of the stand. (Bruce Clayton photo.)*

and Four). It is, however, conceivable that successful invasion could occur under a frequent fire regime if those fires were always of low intensity. As noted earlier, Keown's (1977) light fires only killed 20 percent of the invading limber pines, while his high intensity fires killed 80 percent of the invaders.

Frequent cool, surface fires could actually favor development of limber pine stands by keeping fuels from reaching levels that would support severe tree-killing fires. The possibility that Group One sites have been subjected to frequent fires that produce very slight effects (no scarring) cannot be ruled out. The existing evidence, however, seems to favor the interpretation of infrequent fires.

The presence of open stands of mature limber pine and Douglas-fir suggest that these more fire-resistant growth forms can be maintained by periodic fires that clean out the intervening regeneration. Fire can act as a thinning agent that slightly favors limber pine over Douglas-fir in the younger age classes.

As the old burn on Hogback Ridge testifies (fig. 4B), holocaust fires on Fire Group One sites are a possible if rare event. A wind-driven crown fire can destroy a stand, especially if enough time has passed since the last ground fire to allow a layer of regeneration, shrubs, or litter and other debris to form under the trees. Several of the Group One sites sampled for the Montana habitat type data base showed signs of origin following fire. Limber pine probably reestablished on these sites as a result of seed cached in the soil by Clark's nutcrackers (Lanner and Vander Wall 1980).

## Generalized Forest Succession

A generalized concept of forest succession in Group One habitats and how fire affects this succession is shown in figure 5 (subsequent numbers in this section refer to fig. 5).

Grassland sites that are potential PIFL habitat types are maintained as grassland by frequent grass fires (No. 1). It is uncertain to what extent this effect is taking place, and also the frequency of fire required to prevent conifer invasion of the grassland is not known. Where conifers have succeeded in growing to maturity, the apparent frequency of fire is low (once or twice a century).

A shrub stage following the grassland stage has been implied in certain PIFL habitats but not in others. The shrub stage is, for example, usually lacking on PIFL/AGSP and PIFL/FEID h.t.'s. The shelter provided by the shrubs when they do occur apparently helps limber pine and Douglas-fir seedlings to become established. A thinning fire in the sapling period eliminates the shrubs (temporarily) and tends to favor limber pine over Douglas-fir (No. 2). Further regeneration may require the reestablishment of the shrub cover in habitats where shrubs are a factor. A severe fire in sapling stage can kill most of the trees, reverting the site to the grassland condition (No. 3).

If a fire-free period occurs long enough (it usually does), the limber pine and Douglas-fir trees reach maturity and acquire some fire resistance due to their thick bark. Subsequent fires tend to thin the stand, leaving the mature trees in an open fire-maintained stand (No. 4).

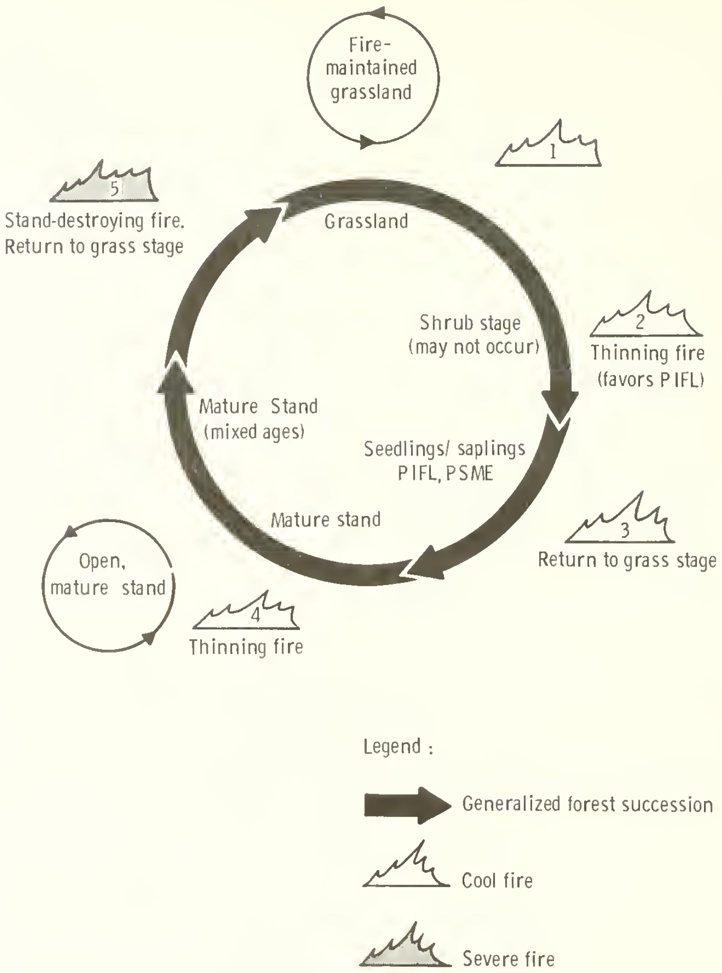



*Figure 5.—Generalized forest succession in Fire Group One: limber pine climax series habitat types.*

If fire does not thin the mature forest over a very long period (possibly centuries), then accumulating regeneration and litter could eventually contribute to a wind-driven, stand-destroying wildfire (No. 5). Such a severe fire reverts the site to a grassland condition, possibly for a very long time. Regeneration depends on the local availability of seed and the subsequent fire history.

## Successional Pathways

Forest succession on this group's habitat types is not well understood. Research is especially needed to define fire frequency, rates of succession, and limber pine fire resistance. The role of fire in limber pine seedling establishment also needs investigation. Hypothetical successional pathways that may be followed by Fire Group One communities are shown in figure 6 (subsequent states and numbers in this section refer to fig. 6). Six states or stages of vegetative development are recognized for Group One habitats.

State A is grassland. Frequent fire at relatively short intervals maintains this state (No. 1).

Low fire frequency may result in establishment of a shrub stage (state B). Any fire occurring during this stage will revert the site to grassland (No. 2).

Absence of fire for a long interval allows the successful invasion of limber pine and Douglas-fir seedlings (state C). A moderate to severe fire during this state reverts the site to grassland (No. 3). A light surface fire in the sapling stage may merely thin out some individual trees and not significantly affect succession (No. 4).

State D is the mature forest. A severe fire in this state reverts the site to grassland (No. 5). Light ground fires burning through mature stands tends to thin out regeneration and undergrowth, leaving open stands of mature trees (No. 6). The resulting coniferous woodland is shown as state F. Periodic low severity fires will maintain the coniferous woodland state (No. 7). A severe fire during state F will revert the site to grassland (No. 7).

In the absence of fire, the mature stand (state D) will develop into a dense, mixed-age climax stand of limber pine, Douglas-fir, and Rocky Mountain juniper (state E). This state will perpetuate itself in the continued absence of fire. A cool fire during state E thins out regeneration, undergrowth, and some overstory trees (No. 8). This has the effect of creating the coniferous woodland state (state F). A severe fire during state E reverts the site to grassland (No. 9).

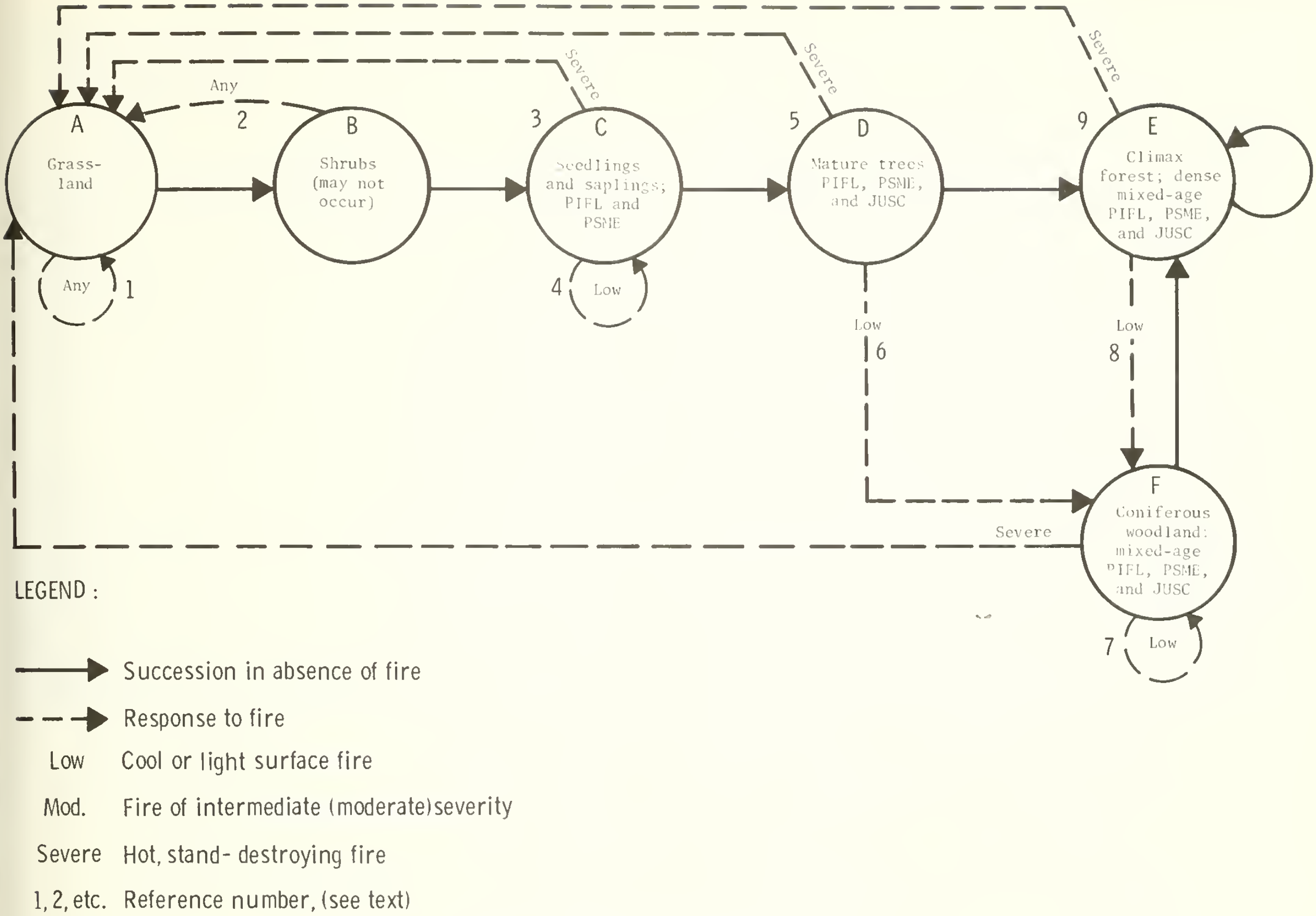



*Figure 6.—Hypothetical fire-related successional pathways for Fire Group One habitat types.*

## Fire Management Considerations

Resource productivity is usually low on Group One habitats. Consequently, high fire suppression expenditures are rarely justified except when life, private property, adjoining areas of high value resources, or improvements are seriously threatened. Open stands with sparse ground cover often act as firebreaks under most burning conditions.

Periodic light surface fires can benefit browse and forage production for wildlife and domestic livestock on those sites where this is an important management objective. Keown (1977) has demonstrated the use of prescribed fire for checking conifer invasion and otherwise improving range and wildlife habitat on certain Group One sites. He received good results using the following prescription:

| | |
|---|---|
| Temperature | greater than 50° F (10° C) |
| Relative humidity | 30 percent or less |
| Wind | 5–15 mi/h (8–24 km/h) |
| Fuel moisture | 5–10 percent |
| Soil moisture | damp |

The most significant prescription condition was sun shining on the burn unit. Humidity recovery at night was important for cooling smoldering logs and duff. Wind had to be strong enough to spread the fire but light enough to allow the heat from the fire to scorch crowns of unwanted trees.

Results of spring burning according to the above prescription included a definite stimulation of grass, forbs, shrubs, and aspen. Comparison of prefire and postfire vegetative cover showed a 50 percent increase in forb coverage, a 40 percent decrease in grass coverage, and a 47 percent decrease in shrub coverage the first season after fire. A general increase in the protein content of browse plants important to wildlife was noted (Keown 1977).

## FIRE GROUP TWO: WARM, DRY PONDEROSA PINE HABITAT TYPES

| ADP code | Habitat type-phase (Pfister and others 1977, Roberts 1980, Roberts and Sibbernsen 1979) | Montana forest region (Arno 1979) |
|---|---|---|
| 110 | *Pinus ponderosa/Andropogon* spp. h.t. (PIPO/AND), ponderosa pine/bluestem. | Southeastern. |
| 130 | *Pinus ponderosa/Agropyron spicatum* h.t. (PIPO/AGSP), ponderosa pine/bluebunch wheatgrass. | Central and southeastern (including Bearpaw Mountains). |
| 141 | *Pinus ponderosa/Festuca idahoensis* h.t.-*Festuca idahoensis* phase (PIPO/FFID-FEID), ponderosa pine/Idaho fescue-Idaho fescue phase. | Central and southeastern. |
| 142 | *Pinus ponderosa/Festuca idahoensis* h.t.-*Festuca scabrella* phase (PIPO/FEID-FESC), ponderosa pine/Idaho fescue-rough fescue phase. | Central (including Bearpaw Mountains). |
| 161 | *Pinus ponderosa/Purshia tridentata* h.t.-*Agropyron spicatum* phase (PIPO/PUTR-AGSP), ponderosa pine/bitter-brush-bluebunch wheatgrass phase. | Central. |
| 162 | *Pinus ponderosa/Purshia tridentata* h.t.-*Festuca idahoensis* phase (PIPO/PUTR-FEID), ponderosa pine/bitter-brush-Idaho fescue phase. | Central. |
| 171 | *Pinus ponderosa/Symphori-carpos albus* h.t.-*Symphori-carpos albus* phase PIPO/SYAL-SYAL), ponderosa pine/snowberry-snowberry phase. | Central and southeastern. |
| | *Pinus ponderosa/Juniperus horizontalis* h.t. (PIPO/JUHO), ponderosa pine/horizontal juniper. | Central (Little Rocky Mountains only). |
| | *Pinus ponderosa/Symphori-carpos occidentalis* h.t. (PIPO/(PIPO/SYOC), ponderosa pine/western snowberry. | Central (Little Rocky Mountains only). |
| | Pinus ponderosa/*Arcto-staphylos uva-ursi* h.t. (PIPO/ARUV), ponderosa pine/kinnikinnick. | Central (Little Rocky Mountains only). |
| | *Pinus ponderosa/Juniperus scopulorum* (PIPO/JUSC), ponderosa pine/Rocky Mountain juniper. | Central (Missouri River Breaks only). |

Fire Group Two consists of ponderosa pine stands with predominantly grass undergrowth. These habitats may exist as fire-maintained grassland and will support limber pine, Rocky Mountain juniper, and Douglas-fir as accidental individuals. In some habitat types, juniper may be a minor climax species. Sites are typically hot, dry, south- and west-facing slopes at low elevations, forming the lower timberline in the area. Slopes are often steep with poorly developed soils. Extensive stands also occur on flats and rolling topography at the lowest elevation of forest distribution. Moisture stress is a critical factor for plant growth during summer months. Stockability limitations often result in low productivity although some sites regenerate readily and form dog hair thickets.

### Forest Fuels

Downed and dead fuel loads in Group Two stands are often light. The amount of material less than 3 inches (7.6 cm) in diameter rarely exceeds 5 tons/acre (1 kg/m$^2$). The amount of material greater than 3 inches (7.6 cm) varies according to stand condition but usually accounts for 75 percent or more of the total load (table 4). The large fuels result from the downfall of dead trees that were unsuccessful competitors in dense stands, from deadfall following fire, and from mechanical damage caused by wind, snow, or overstory removal (fig. A).

Live fuels may contribute to fire hazard in Group Two stands. Dense ponderosa pine understories often develop beneath scattered overstory trees on some Group Two sites (fig. 7B). Fires that start in such stands often burn vigorously in the crowns of the understory trees. Consequently, fast spreading, severe fires result despite relatively light downed and dead fuel loadings.

Figure 8 shows actual stand conditons on some Fire Group Two habitat types on the Custer National Forest. Corresponding fuel loads are given in table 5.

*Figure 7.—Fire Group Two ponderosa pine stands, Ashland-Fort Howes Ranger District, Custer National Forest. (A) Stand with large diameter downfall. (B) Dense understory beneath scattered overstory. (Bruce Clayton photo.)*

**Table 5.**—Fuel loading by size class for Fire Group Two stands shown in figure 8.

| Stand number | Habitat type | Age | Duff depth | Size class (inches) | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0-1/4 | 1/4-1 | 1-3 | 3-6 | 6-10 | 10-20 | |
| | | *Years* | *Inches* | *Tons/acre* | | | | | | |
| 33A | PIPO/SYAL-SYAL | 180 | 1.7 | 0.3 | 1.0 | 0.5 | 0.5 | 0.2 | 3.2 | 5.7 |
| 30A | PIPO/SYAL-SYAL | 60 | 1.1 | 0.2 | 0.6 | 1.9 | 0.7 | 2.4 | 0.9 | 6.7 |
| 32A | PIPO/FEID-FEID | 58 | 1.1 | 0.5 | 1.9 | 4.5 | 1.0 | 2.5 | 0 | 10.4 |
| 31A | PIPO/FEID-FEID | 148 | 0.8 | 0.2 | 0.4 | 0.7 | 1.0 | 2.8 | 5.5 | 10.7 |
| 29A | PIPO/FEID-FEID | 100 | 0.4 | 0.2 | 1.3 | 3.2 | 3.4 | 0.9 | 2.4 | 11.4 |


*Figure 8.—Examples of Fire Group Two ponderosa pine stands, Ashland-Fort Howes Ranger District, Custer National Forest. Stands 33A and 30A (A and B) are on a ponderosa pine/snowberry h.t.-snowberry phase. Stands 32A, 31A, and 29A (C, D, and E) are on ponderosa pine/Idaho fescue h.t.-Idaho fescue phase. Stand 29A was recently burned. The cat face in stand 31A (D) is evidence of past fire.*

## Role of Fire

The role of fire in Group Two habitats is threefold:

1. **To maintain grasslands.** Grassland areas capable of supporting juniper and ponderosa pine may remain treeless through frequent burning.

2. **To maintain open pine stands**. The open condition is perpetuated by periodic fires that either reduce the number of seedlings, remove dense understories of sapling or pole-sized trees, or thin overstory trees.

3. **To encourage ponderosa pine regeneration**. Fire exposes mineral soil, reduces seedling-damaging cutworm populations, reduces competing vegetation, and increases nutrient availability. Depending on the subsequent seed crop, weather, and continuity of the seedbed, regeneration may appear as dense stands, separated thickets, or scattered individuals. Periodic fires can create uneven-aged stands comprised of various even-aged groups. Severe fires will result in a predominantly even-aged stand.

Natural fire frequencies in forests adjacent to grasslands were fairly high, according to numerous fire history studies conducted in the ponderosa pine forest types throughout the Western States. These studies have shown fire to have been a frequent event, occurring at intervals of from 5 to 25 years in most locations. In Group Two habitat types of the Bitterroot National Forest, Arno (1976) reported a range of 2 to 20 years and mean fire-free intervals of 6 to 12 years for fires occurring somewhere in small stands, 50 to 100 acres (20 to 40 ha) (Arno 1981). Fire history investigators caution that these figures are conservative estimates of past mean fire-free intervals. Intervening light ground fires could have effects on stand development without leaving scars on trees.

A fire frequency of 50 years or more is suggested by Wright (1978) for the PIPO/PUTR h.t. He bases this hypothesis on observation and current knowledge of the susceptibility of bitterbrush to fire (Nord 1965; Weaver 1967; Wright 1978). Other investigators, however, suggest that ponderosa pine communities with shrub understories experienced fire frequencies of considerably less that 50 years (Gruell and others 1981; Weaver 1957, 1959, 1961).

Successful fire control during the 20th century has undoubtedly affected some Group Two stands. A primary effect is the increased presence of two-storied stands on some sites where the understory is a dense stand of pole-sized or larger trees (fig. 7). When fire control eventually fails in such stands, large, severe fires often result. Another effect of fire control is an increase in the acreage covered by Group Two stands as a result of successful juniper and ponderosa pine invasion of formerly fire-maintained grasslands. In hot, dry areas where natural regeneration is extremely slow and stocking is limited, the effect of fire control has often been minimal.

## Generalized Forest Succession

A generalized concept of forest succession in Fire Group Two habitats and how fire affects this succession is shown in figure 9 (subsequent numbers in this section refer to fig. 9).

Very frequent fires tend to maintain the grassland community by killing pine seedlings (No. 1). Grasses dominate the

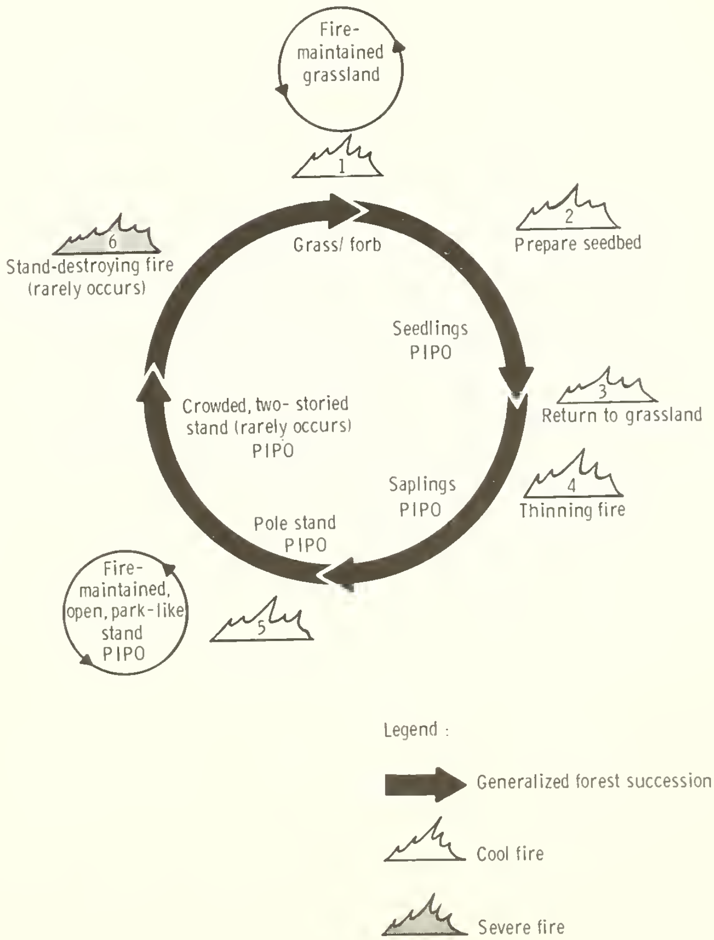



*Figure 9.—Generalized forest succession in Fire Group Two: warm, dry ponderosa pine habitat types.*

undergrowth, but other herbs and small shrubs may be present. Ponderosa pine seedlings may become established gradually over a long fire-free period resulting in an all-aged, all-sized stand; or as a single age class following a seedbed-preparing fire (No. 2). In the absence of further burning, the seedlings develop into saplings. Fires during this period may have the effect of killing the young trees (No. 3) or thinning them (No. 4).

With sufficient time the remaining trees mature to pole-size saplings. Subsequent light ground fires tend to produce an open stand of mature trees (No. 5). The open nature of the stand is a direct result of the fires and stocking limitations, and deteriorates if the fires are suppressed. The stand may then (in theory) become overstocked and accumulate enough fuel to support a severe stand-destroying fire (No. 6). In practice this situation is seldom observed in Group Two stands.

## Successional Pathways

The combined effects of fire, plant succession, and fire exclusion are hypothesized in figure 10 (subsequent states and numbers in this section refer to fig. 10). Starting with an open, parklike stand (state A), and assuming a long fire-free interval, ponderosa pine seedlings of various ages and sizes will become established (state B1). Any fire during state A will create a mineral soil seedbed and likely result in the establishment of even-aged ponderosa pine seedlings (state B2).

### UNEVEN-AGED SUCCESSION

Any fire occurring in the uneven-aged seedling state (state B1) will return the site to state A, the open, parklike stand (No. 1). The absence of fire will allow the development of a

I. SUCCESSION FROM THE OPEN, PARKLIKE, OLD GROWTH PONDEROSA PINE STATE

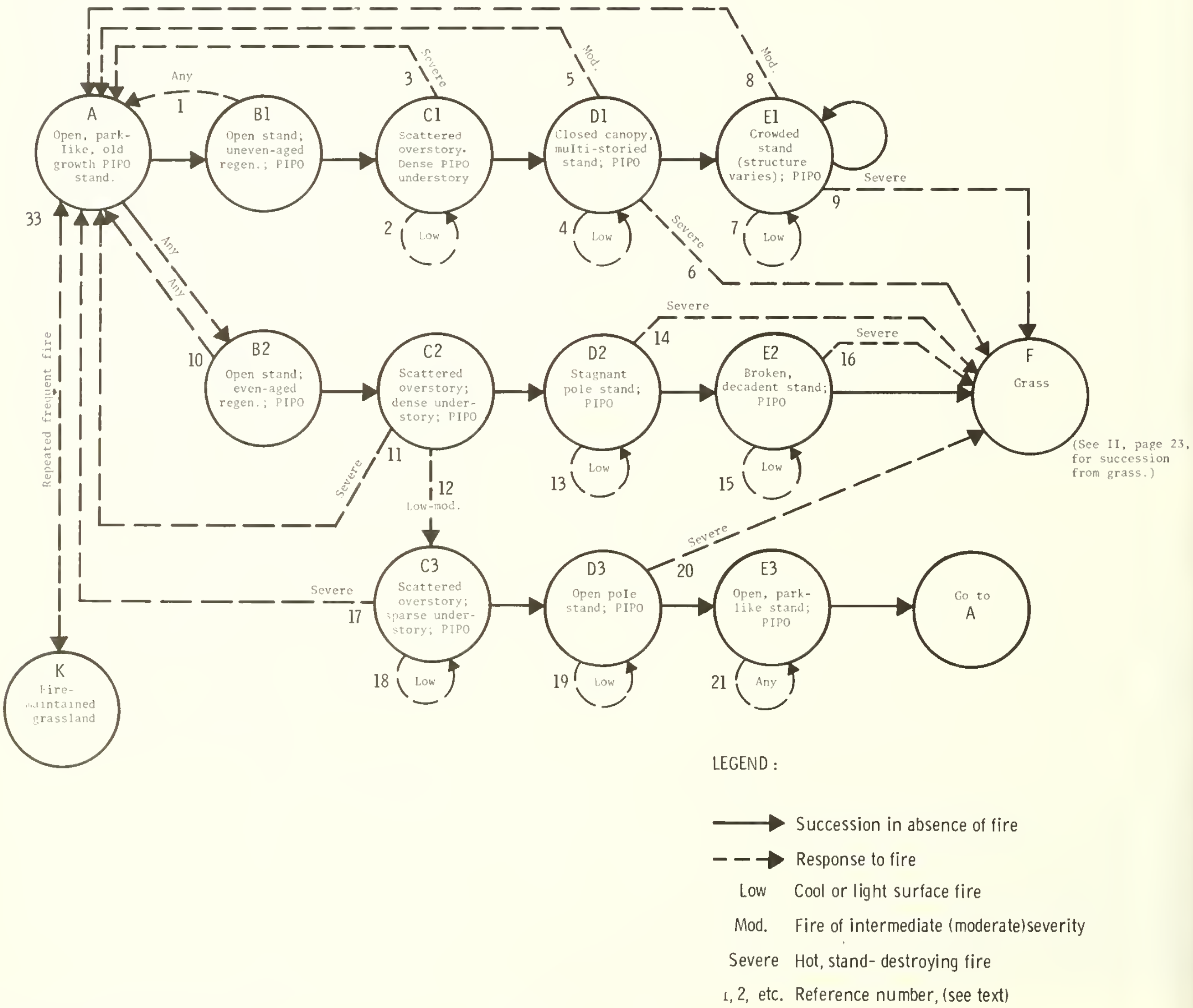



*Figure 10.—Hypothetical fire-related successional pathways for Fire Group Two habitat types.*

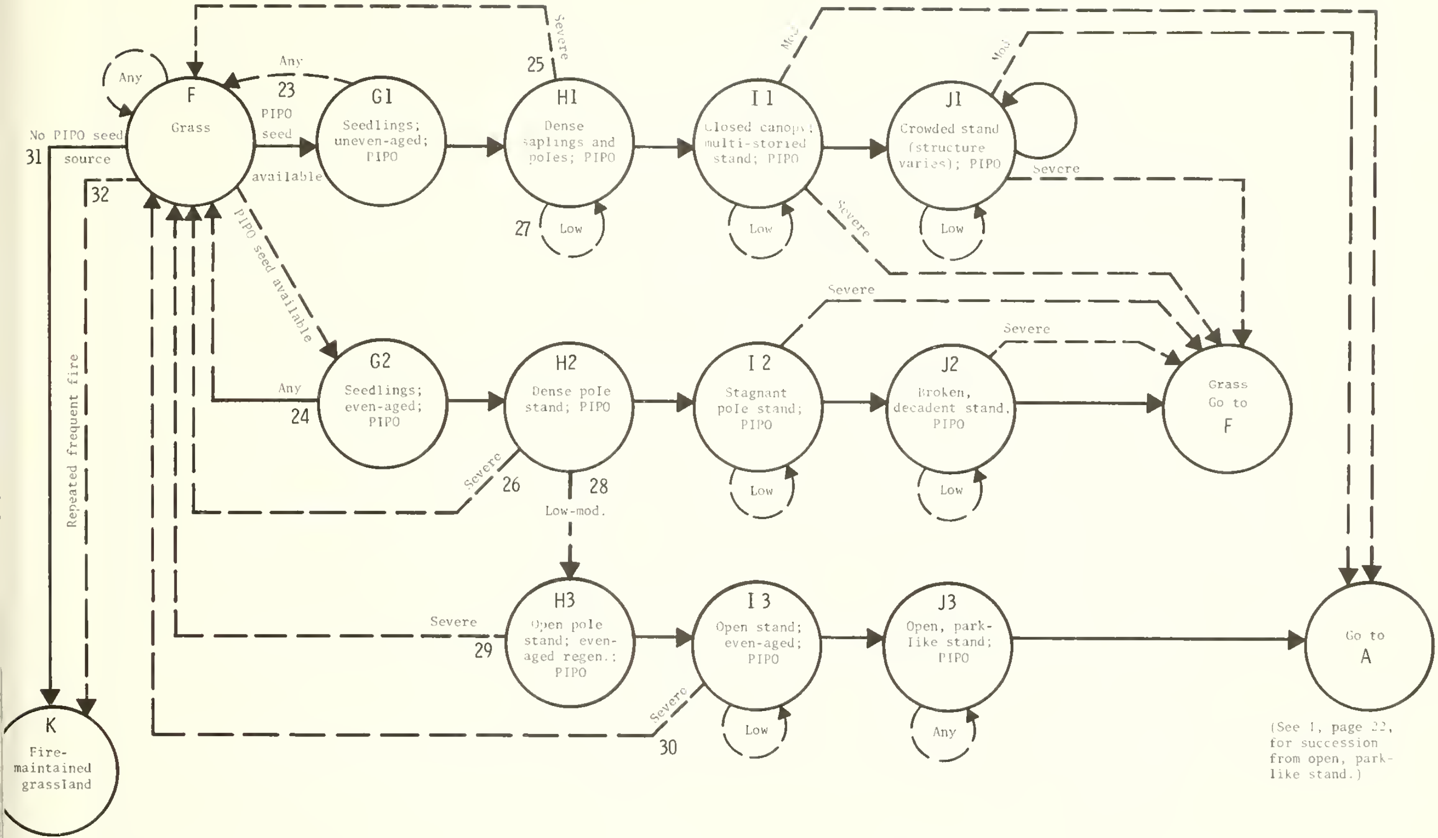



*Figure 10.—(con.)*

dense uneven-aged understory of ponderosa pine saplings and poles (state C1). A light surface fire at this state would act as a thinning fire removing some saplings from the stand (No. 2). A severe fire would return the site to the open parklike state (No. 3). Continued absence of fire allows a multistoried stand with a closed canopy to develop (state D1). A cool fire would have little impact on such a stand (No. 4). A moderate to severe fire could remove undergrowth and understory trees, and kill many overstory trees. This would result in the development of an open, parklike stand (No. 5). A severe, wind-driven crown fire might kill all trees and leave the site in grass (No. 6). Without fire, a crowded stand of mature ponderosa pine with a varied understory could develop and persist on the site (state E1). A cool fire would not have much impact except in the undergrowth (No. 7). A moderate to severe fire could remove much of the vegetation and leave an open, parklike stand (No. 8). A fire that kills all the trees would leave the site in grass (No. 9).

## EVEN-AGED SUCCESSION

Succession following the establishment of even-aged seedlings (state B2) can be quite different from that occurring in the uneven-aged seedling state. Any fire during the even-aged seedling state will maintain the open, parklike conditions (No. 10). The absence of fire will allow a dense even-aged understory to develop (state C2). A severe fire in this state will revert the site to the open, parklike condition (No. 11), but a low to moderately severe fire might thin out the dense understory (No. 12) and leave an open stand with a sparce understory (state C3). Without a thinning fire, the dense, even-aged understory state (C2) could develop into a stagnant stand of even-aged, pole-sized trees (state D2). A light surface fire would have minimal impact on this condition (No. 13), and a severe fire would destroy the stand and leave the site in grass (No. 14). A continued absence of fire would result in a broken, decadent stand (state E2). A light surface fire in this state (E2) would do little to change stand conditions (No. 15). A severe fire (No. 16) or a continued lack of fire would lead to the grass state (state F). If fire thins out the dense understory associated with state C2 (No. 12), a different succession is likely. The resulting scattered overstory/sparse understory state (state C3) will revert to the open, parklike condition if severely burned (No. 17). A light surface fire should have little effect (No. 18). The absence of fire, however, will allow the development of an open pole stand (state D3), which could eventually develop into a open parklike stand (state E3). A surface fire would not interfere with this succession (No. 19), but a severe fire would likely destroy the stand (No. 20). Any fire occurring in the open, parklike stand would have little effect on the overstory trees (No. 21).

## SUCCESSION FROM THE GRASS STATE

If a seed source is present, the grass state (state F) is eventually replaced by forest. Tree regeneration may occur as even-aged seedlings following a fire (state G2) or as uneven-aged seedlings on undisturbed grass sites (state G1). Any fire occurring during the seedling state (No. 23 and 24) will return the site to grass.

If fire is absent for long enough, dense stands of uneven-aged saplings and poles (state H1) or even-aged poles (state H2) develop. Severe fires return the sites to grass (No. 25 and 26). A cool fire will reduce the density of both the uneven-aged and the even-aged stands (No. 27 and 28).

Succession proceeds as outlined for open, parklike stands except that severe fires in states H3 and I3 return the sites to grass (No. 29 and 30) rather than to the open, parklike condition.

If a site becomes dominated by grass following a fire that destroys the only available seed source, a grassland may be created (No. 31). Frequent fire at intervals short enough to keep seedlings from attaining sapling or pole size will also maintain a site as grassland (No. 32). An open, parklike stand may also revert to grassland if repeated fire maintains the site in grass until the overstory trees die (No. 33).

## Fire Management Considerations

Fire can be used to accomplish a variety of forest management objectives in Fire Group Two stands. These objectives include wildfire hazard reduction, forage production, site preparation for tree regeneration, stocking control, and development and maintenance of recreation sites.

### WILDFIRE HAZARD REDUCTION

Prescribed fire can reduce dense patches of small trees and accumulated dead grass, needles, and woody debris in stands of pole-sized and larger trees, thereby lessening the chance of tree-killing wildfires. Similarly, slash hazard can be reduced by broadcast burning after cutting. In order to maintain a low level of flammability in Group Two stands, fire must be applied periodically whenever sufficient fuel accumulates to carry fire. Where heavy fuel loads exist prior to the initial entry with prescribed fire, it is often best to plan several burns in successive years rather than to risk the cambium kill and crown scorch often associated with a hot fire. Fuels can also be reduced through firewood removals, and piling and burning during safe periods.

### FORAGE PRODUCTION

Forage production for livestock and big game can be enhanced by proper application of fire on Group Two habitat types. On PIPO/AND h.t.'s, PIPO/AGSP h.t.'s, and PIPO/FEID h.t.'s, grasses can be rejuvenated by removing dead grass and releasing stored nutrients. Fire can result in an increased production of nutrient-rich forbs. On PIPO/SYAL h.t.'s, light surface fires will rejuvenate shrubs through fire-simulated sprouting and cause a temporary increase in grass and forb production. Fire may be difficult to apply on open, heavily grazed PIPO/PUTR h.t.'s, where percent cover by plants is low and litter is sparse. Where it will carry, fire can be used to rejuvenate the undergrowth by killing decadent bitterbrush and thereby regenerating the site from onsite sprouting or from offsite seed cached in the burn by rodents. As a general rule, luxuriant growth of shrubs will not result from fire use on Group Two habitat types.

### SITE PREPARATION AND STOCKING CONTROL

Fire can create a mineral soil seedbed where this is necessary for successful ponderosa pine regeneration. Once a new stand is established and an adequate number of trees 10 to 12 ft (3 to 3.7 m) or taller comprise the overstory, fire can be used to remove unwanted understory trees (Wright 1978). Subsequent use of fire at 5- to 7-year intervals will remove unnecessary reproduction and accumulated dead woody fuel, thereby increasing stand vigor, reducing fire hazard, and increasing grass, forb, and shrub production (Wright 1978). Siemens[1] suggests the following schedule of prescribed fire use for silvicultural purposes in Group Two ponderosa pine stands:

1. Use fire to prepare seedbed.
2. Protect regeneration from fire for 10 years.
3. Use a cool fire to remove smaller trees and thin some taller trees.
4. Protect stand for approximately 10 more years or until it is ready for precommercial thinning.
5. One year before commercial thinning, use fire to remove surface fuels and kill some of the trees.
6. Thin stand and protect from fire for about 5 years to allow slash to settle.
7. When slash is settled, use fire to consume these fuels.
8. Conduct cool fires about every 10 years to keep stand fuel free.

### RECREATION SITE DEVELOPMENT

Prescribed fire can be used to create parklike openings underneath mature stands of ponderosa pine in which campgrounds and picnic areas can be installed. Periodic use of fire in spring or fall will maintain such openings and reduce fire hazard.

[1]Roger M. Siemens, District Forest Ranger Big Timber Ranger District Gallatin National Forest, Big Timber, Montana. Personal communication, Feb. 2, 1979.

## FIRE GROUP THREE: WARM, MOIST PONDEROSA PINE HABITAT TYPES

| ADP code | Habitat type-phase (Pfister and others 1977, Roberts 1980) | Montana forest region (Arno 1979) |
|---|---|---|
| 172 | *Pinus ponderosa/Symphoricarpos albus* h.t.-*Berberis repens* phase (PIPO/SYAL-BERE), ponderosa pine/snowberry-creeping Oregon grape phase. | Central and southeastern. |
| | *Pinus ponderosa/Amelanchier alnifolia* h.t. (PIPO/AMAL), ponderosa pine/serviceberry. | Central (Bearpaw Mountains only). |
| | *Pinus ponderosa/Berberis repens* h.t. (PIPO/BERE), ponderosa pine/creeping Oregon grape. | Central (Little Rocky Mountains only). |
| 181 | *Pinus ponderosa/Prunus virginiana* h.t.-*Prunus virginiana* phase (PIPO/PRVI-PRVI), ponderosa pine/chokecherry-chokecherry phase. | Southeastern. |
| 182 | *Pinus ponderosa/Prunus virginiana* h.t.-*Shepherdia canadensis* phase (PIPO/PRVI-SHCA), ponderosa pine/chokecherry-buffaloberry phase. | Southeastern. |

Fire Group Three ponderosa pine stands are more moist and slightly cooler than those of Group Two. This is the result of increased growing season precipitation and the infrequency of severe drought. Group Three stands are usually found in ravines or on north slopes. A relatively deep duff layer of about 1.5 to 2.5 inches (46 cm) covers the characteristically rock-free silt loam soils of these stands. Ponderosa pine and occasionally Rocky Mountain juniper are the only successful conifers. A rather lush undergrowth of shrubs and the absence of stocking limitations for ponderosa pine reflect the favorable moisture conditions. Pine regeneration frequently forms dense dog hair thickets. Stand structure is variable. Some stands appear to be all-aged, with scattered regeneration and rather uniform representation of size classes. Other stands show two (fig. 11) or even three distinct size classes (Pfister and others 1977).

### Forest Fuels

Downed and dead fuel loads in Group Three stands are light, not unlike those of Group Two stands (fig. 11). Total average loading is slightly higher than the Group Two average (table 4 and fig. 2). Downed woody material less than 3 inches (7.6 cm) in diameter averages less than 3 tons/acre (0.7 kg/m$^2$). The amount of material greater than 3 inches (7.6 cm) averages about 10 tons/acre (2.2 kg/m$^2$).

Live fuels in the form of dense dog hair thickets of ponderosa pine saplings create a definite fire hazard in Group Three stands. The tendency toward multistoried stands results in a high probability of crown fires (fig. 11).

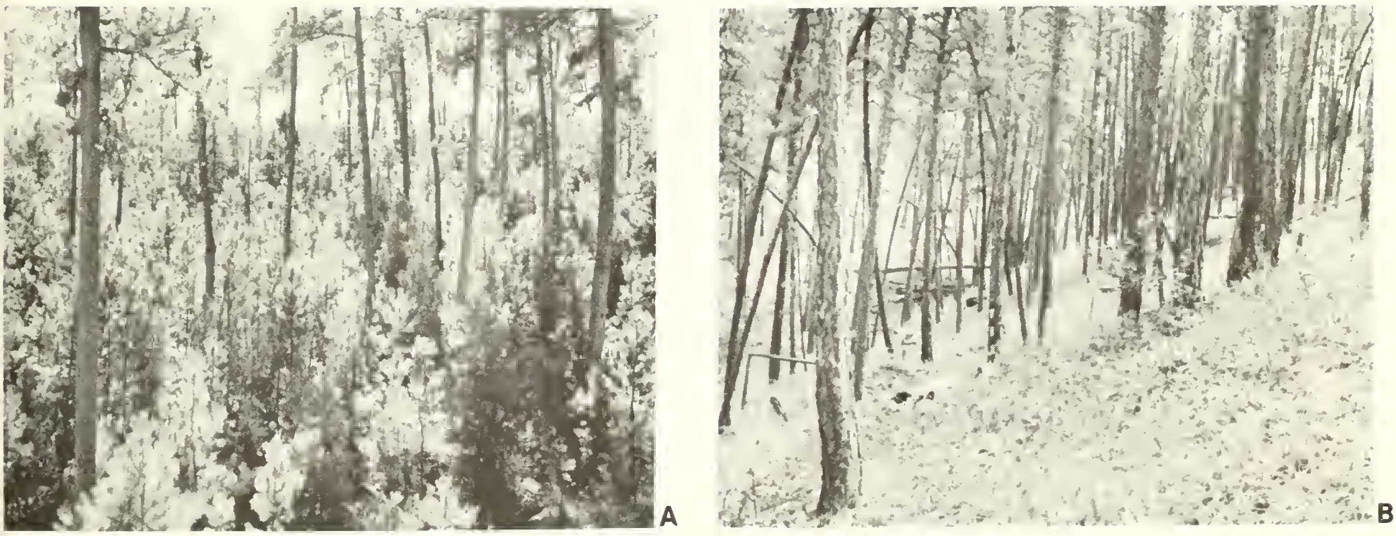



*Figure 11.—Examples of Group Three ponderosa pine stands in eastern Montana. (A) A two-storied stand with a very dense understory. (B) Well-stocked ponderosa pine stand on a ponderosa pine/chokecherry h.t. Forest floor is shrub covered and downed woody fuel loading is light.*

## Role of Fire

Authoritative information about the role of fire in Fire Group Three stands during presettlement times is scant. It seems, however, that fire:

1. Prepared seedbeds favorable for ponderosa pine regeneration,
2. Controlled stocking levels during the seedling and sapling stage of tree development,
3. Thinned out suppressed pole-sized ponderosa pine trees,
4. Maintained mature stands in an open, parklike condition,
5. Provided some browse for wildlife, and
6. Destroyed dense, stagnant, and multistoried stands,

Fire's present role is essentially the same as during presettlement times. The major difference is the frequency of stand-replacement fires. This is due in large part to successful fire exclusion programs during modern times. Such programs have allowed the rather widespread development of dense, stagnant, and multistoried stands on Group Three sites. When fire suppression fails and burning conditions are favorable, severe wind-driven crown fires often occur in such stands. Periodic cool surface fires minimized the occurrence of such high-hazard stand conditions during presettlement times.

## Generalized Forest Succession

Existing mature stands on Fire Group Three sites tend to be all-aged with scattered regeneration or stands with two or even three distinct size classes (Pfister and others 1977). Broken stands of stagnant poles, the remnants of dog hair thickets, can also be considered a mature forest situation. A severe fire in such stands results in destruction of the stand and preparation of a mineral soil seedbed, as shown in figure 12, No. 1 (subsequent numbers in this section refer to fig. 12). Shrubs and herbs already present on the site will dominate following fire. Frequent fires (double or triple burns) occurring during this stage could maintain the site in shrubs and herbs (fig. 12, No. 2). This is, however, an uncommon occurrence. Abundant ponderosa pine seedlings usually become established following fire and eventually dominate the site. A fire at this stage of succession returns the site to a shrub/herb condition (No. 3). Depending on initial seedling densities and subsequent mortality, the sapling stage may or may not take the form of a dog hair thicket. Fires occurring in such thickets can be more severe than those occurring in less dense sapling stands. Such a fire would return the site to shrubs and herbs (No. 4). A light

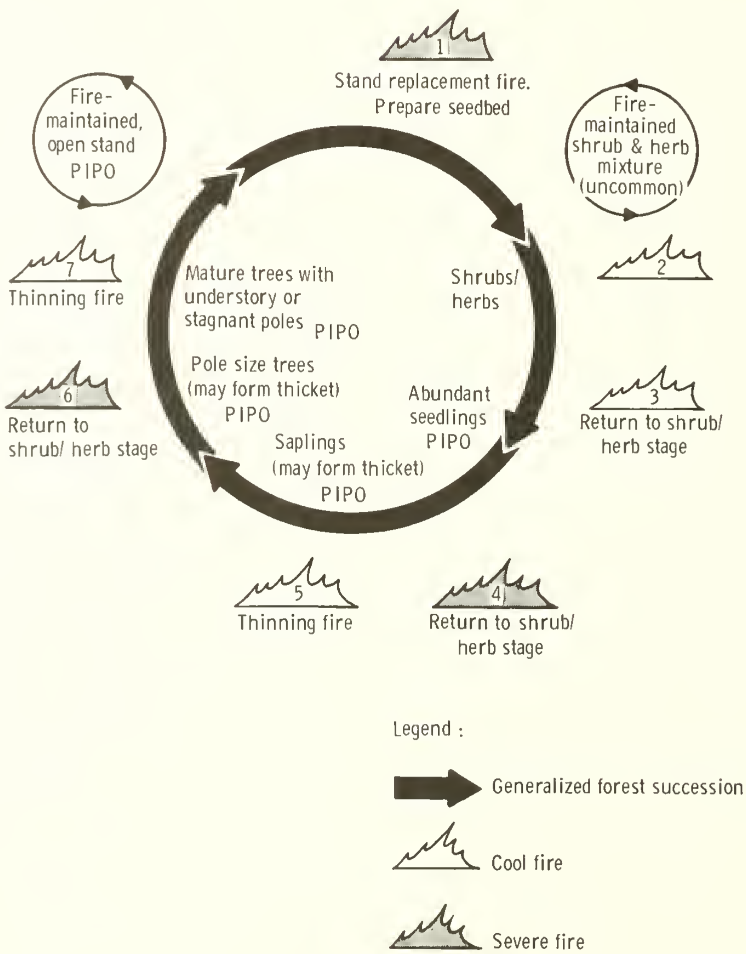


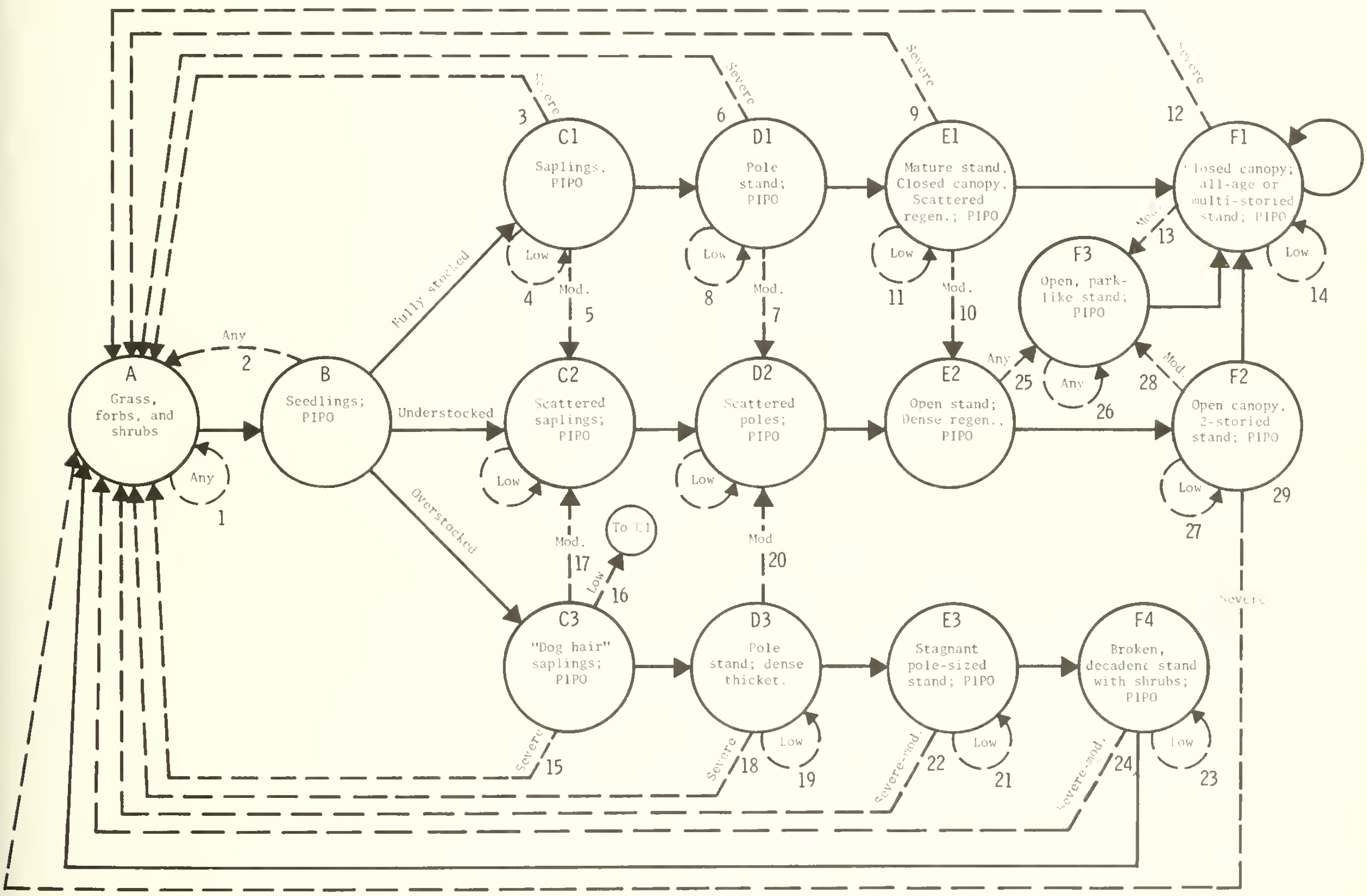

*Figure 12.—Generalized forest succession in Fire Group Three: warm, moist ponderosa pine habitat types.*

surface fire would likely thin out susceptible stems thereby reducing stocking (No. 5). The effect of fire is similar in pole-size and mature stands of ponderosa pine on Group Three sites. Severe fires are likely in thickets and would result in a return to the shrub/herb state (No. 6). A moderate severity fire will either reduce stocking levels in crowded pole-size trees or remove regeneration in mature stands (No. 7). Frequent cool to moderate fires can maintain stands in an open, parklike condition. Surface fires in the climax stage would perpetrate the all-age or multistory condition by preparing seedbed for ponderosa pine regeneration.

## Successional Pathways

Many of the successional states and pathways hypothesized for Fire Group Two ponderosa pine stands (fig. 10) also apply to Fire Group Three stands. The major difference is that Group Three stands tend more toward the dense all-age and multistory condition than to the open, parklike condition shown for Group Two.

On Group Three sites a shrub/herb state usually follows a stand replacement fire, as shown in figure 13, state A (subsequent states and numbers in this section refer to fig. 13). This state could be maintained by frequent fire (No. 1). Very frequent repeated fires favor grass at the expense of shrubs. Abundant ponderosa pine seedlings usually become established and soon dominate the postfire community (state B). The abundance and subsequent mortality of seedlings is an important factor in determining succession. If the site is greatly overstocked with seedlings, a dense dog hair thicket may develop (state C3). If the number of surviving seedlings approximates a fully stocked condition, succession will follow a different path




LEGEND:

| | |
|---|---|
| ——▶ | Succession in absence of fire |
| – – ▶ | Response to fire |
| Low | Cool or light surface fire |
| Mod. | Fire of intermediate (moderate) severity |
| Severe | Hot, stand-destroying fire |
| 1, 2, etc. | Reference number, (see text) |

*Figure 13.—Hypothetical fire-related successional pathways for Fire Group Three habitat types.*

(state C1). Understocking is not common on fire-created mineral soil seedbeds on these sites. Understocking can occur, however, as a result of fire or other factors (for example, red belt injury caused by extreme winter weather conditions). The understocked condition is state C2.

### FULL STOCKING CONDITION

A severe fire would likely destroy a sapling stand and return the site to shrubs and herbs (No. 3). A light surface fire would have minimal effect (No. 4), but a moderately severe fire might kill a majority of the saplings (No. 5) and leave an understocked condition (state C2).

In the absence of fire a fully stocked pole stand will develop (state D1). A severe fire could destroy such a stand and return the site to shrubs and herbs (No. 6) but a less severe fire might leave scattered live trees on the site (No. 7). A light surface fire would have little impact (No. 8). The lack of fire in a fully stocked pole stand should result in a closed canopy stand of mature trees with scattered regeneration in the understory (state E1). Again, a severe fire could recycle the site to shrubs and herbs (No. 9). A fire of moderate severity might thin out the overstory and leave an open stand (No. 10). Dense regeneration would probably develop on the fire-prepared seedbed. A light surface fire during state E1 would do little more than kill scattered regeneration (No. 11).

A fully stocked mature stand would develop into a closed canopy all-aged or multistoried climax stand (state F1) in the continued absence of fire. Such a stand would be highly susceptable to a stand replacement fire that would return the site to shrubs and herbs (No. 12). A less severe fire (No. 13) could leave an open, parklike stand (state F3). A cool fire would thin out some understory trees that in time would be replaced by new seedlings (No. 14).

### DOG HAIR THICKETS.

Dense dog hair thickets of ponderosa pine saplings (state C3) burn readily and are destroyed by a hot fire (No. 15). Under less than severe burning conditions, fire might cause either a light thinning of stems resulting in a fully stocked state (No. 16), or a heavy thinning that leaves only scattered saplings on the site (No. 17). In the absence of fire, dog hair sapling thickets become dense stands of pole-sized trees (state D3). Severe fire will likely revert the site to shrubs and herbs (No. 18) and a cool fire may have little or no effect (No. 19). A moderately severe fire could leave scattered pole-sized trees on the site (No. 20). If fire or some other thinning agent does not affect the stand, it will stagnate (state E3). A light surface fire will do little to alter this state (No. 21), and a severe fire will likely return the site to shrubs and herbs (No. 22). The stagnant stand will break up over time in the absence of fire (state F4). Insects, disease, snow and wind breakage, and suppression mortality will all take their toll. As the stand opens up, a light surface fire may prepare a seedbed for ponderosa pine seedlings and rejuvenate shrubs (No. 23). A severe fire will return the site to shrubs and herbs (No. 24).

### UNDERSTOCKED CONDITION

As mentioned previously, the understocked condition usually results from seedling or sapling mortality rather than from lack of seedlings following site preparation. Severe fires would be unlikely in understocked stands, and cool fires would do little more than kill occasional stems and prepare a seedbed. Succession would, therefore, progress from the scattered sapling state (state C2) through the scattered pole state (state D2) to the open stand with dense regeneration in the understory (state E2). Any fire at this stage of succession would clear out the understory (No. 25) and leave an open, parklike stand (state F3). This open condition would be maintained by frequent fire (No. 26) and tend toward the all-age or multistoried condition (state F1) in the absence of fire.

If fire does not occur during state E2, a two-storied stand will develop (state F2) that would be (1) maintained by a cool fire (No. 27); (2) changed to the open, parklike condition by a moderate severity fire that removes the understory (No. 28); or (3) returned to shrubs and herbs by a severe fire (No. 29). In the absence of fire the stand would tend toward the all-age or multistoried state (state F1).

## Fire Management Considerations

Fire management considerations for Group Three stands are similar to those described for Fire Group Two stands. They include fire suppression, fuel management, and the use of fire for browse production, site preparation, stocking control, and recreation site development.

### WILDFIRE SUPPRESSION

Wildfire hazard is high in many existing Fire Group Three stands. Dense understories, dog hair thickets, and multistoried stands with continuous fuels from the forest floor to the crowns of overstory trees comprise this hazard. The flammability of these live fuels can reach serious levels during drought. Fire suppression is difficult under average burning conditions. When burning conditions are extreme, fire suppression is practically impossible. The only reasonable way to protect high-hazard Group Three stands from unwanted fire is to emphasize fuel management rather than fire suppression.

### FUEL MANAGEMENT

Fuel management should be an important part of stand management on Group Three habitats. The fuel management must go beyond treatment of slash following logging and thinning activities. It must include stocking control because live fuels are the crux of the wildfire problem. This should be easy to accomplish in stands that are being managed for timber production. In these stands, good silviculture is good fuel management, provided slash hazard is adequately reduced following silvicultural treatments. The fuel management objective should be to avoid large unbroken areas that are overstocked. Two-storied stands are easier to keep in a low-hazard condition than three-storied stands or all-aged stands. Fuel management programs aimed at stocking control should recognize the need to leave scattered thickets for wildlife cover.

### FIRE USE

Prescribed fire can be effectively used to reduce slash hazard following logging and thinning. It can be used to thin out overstocked sapling stands and to eliminate dog hair thickets. Fire may not be an appropriate thinning agent if uniform spacing of stems is desirable. Also, fire can damage many trees without killing (thinning) them.

Fire can be used safely to periodically reduce both live and dead surface fuels after potential crop trees have reached a height of 10 to 12 ft (3 to 3.7 m). Fuel reduction fires may also stimulate shrub production.

The use of fire under standing timber entails some risks to the residual trees. Crown scorch can be a problem when burning during the growing season. A light wind and low flames will usually reduce the risk of crown scorch.

Crown scorch may set the stage for bark beetle attack. Fire managers should consider the probability of beetle attack and write fire prescriptions that minimize its occurrence.

More specifically, fire managers should (Fischer 1980):

1. Become familiar with signs of bark beetle activity so the presence of beetles can be detected during field reconnaissance of areas proposed for burning (Martin and Dell 1978). Remember, however, just because you don't see signs of beetles doesn't mean they are not present within their attack range.

2. Become familiar with the timing of beetle flights in the area to be burned. Whenever possible, schedule prescribed fires around these high-risk periods. This is especially important if you plan to thin ponderosa pine stands with fire. Crown scorch is inherent in such a treatment.

3. Avoid scorching tree crowns (unless your objective is to thin the stand). Crown scorch can be predicted. Albini (1976) used equations developed by Van Wagner (1973) to graphically relate crown scorch to flame length for different windspeeds. He also provides aids for estimating flame length. Norum (1977) suggests a procedure for using Albini's charts to estimate crown scorch when writing a fire prescription. This procedure works for any tree species. Fire managers should use these aids when planning fire use in ponderosa pine stands.

If severe crown scorching does occur, the fire manager has a dilemma. Should he or she immediately remove the scorched trees, thereby avoiding the possibility of a beetle infestation? Or should a wait-and-see approach be followed?

Season of the year is important. Ponderosa pine are often only slightly affected by crown scorching that occurs in early spring or late fall. When ponderosa pine are scorched outside the active growing season, cambium injury becomes an important factor, especially with the thinner bark, pole-sized trees. During a certain period of active growth in spring, ponderosa pine is rather easily killed by scorching. Hare (1960, 1965) has suggested several techniques for detecting cambium injury. Unless local experience indicates otherwise, or if severe cambium injury is detected, the fire manager is well advised to go slow with the saw. Scorched trees should be watched closely, especially for signs of *Ips*; if they become infested, the trees should be removed to lessen the chance of adjacent standing green trees being infested.

One final point: as a general rule, ponderosa pine are more susceptible to bark beetle attack during drought. Consequently, the degree of scorching that a tree can sustain and still survive beetle attack is less than it is under more normal moisture conditions.

Another risk associated with understory burning in this group's ponderosa pine stands is the risk of increasing live fuel hazard. An understory burn may, among other things, prepare a mineral soil seedbed. If the stand is open and seed producers are present, a dense seedling understory may develop. This may or may not be desirable depending on the silvicultural prescription under which the stand is being managed.

# FIRE GROUP FOUR: WARM, DRY DOUGLAS-FIR HABITAT TYPES

| ADP code | Habitat type-phase (Pfister and others 1977, Roberts 1980, Roberts and Sibbernsen 1979) | Montana forest region (Arno 1979) |
|---|---|---|
| 210 | *Pseudotsuga menziesii/ Agropyron spicatum* h.t. (PSME/AGSP), Douglas-fir/ bluebunch wheatgrass. | Central, southwestern, and south-central. |
| 230 | *Pseudotsuga menziesii/Festuca scabrella* h.t. (PSME/FESC), Douglas-fir/rough fescue. | Central. |
| 311 | *Pseudotsuga menziesii/ Symphoricarpos albus* h.t.- *Agropyron spicatum* phase (PSME/SYAL-AGSP), Douglas-fir/snowberry-bluebunch wheatgrass phase. | Central. |
| | *Pseudotsuga menziesii/Symphoricarpos occidentalis* h.t.- *Chrysopsis villosa* phase (PSME/SYOC-CHVI), Douglas-fir/western snowberry-hairy goldenaster phase. | Central (Bearpaw Mountains only). |
| | *Pseudotsuga menziesii/Symphoricarpos occidentalis* h.t.- *Shepherdia canadensis* phase (PSME/SYOC-SHCA), Douglas-fir/western snowberry-russet buffaloberry phase. | Central (Little Rocky Mountains only). |
| 324 | *Pseudotsuga menziesii/Calamagrostis rubescens* h.t.-*Pinus ponderosa* phase (PSME/ CARU-PIPO), Douglas-fir/ pinegrass-ponderosa pine phase. | Central. |
| 340 | *Pseudotsuga menziesii/Spiraea betulifolia* h.t. (PSME/SPBE), Douglas-fir/white spiraea | Central and north-central. |
| 350 | *Pseudotsuga menziesii/Arctostaphylos uva-ursi* h.t. (PSME/ ARUV), Douglas-fir/kinnikinnick. | Central and south-central (including Little Rocky Mountains). |
| | *Pseudotsuga menziesii/Berberis repens* h.t.-*Arctostophylos uva-ursi* phase (PSME/BERE-ARUV), Douglas-fir/creeping holly grape-kinnikinnick phase. | Central (Little Rocky Mountains only). |
| | *Pseudotsuga menziessi/Berberis repens* h.t.-*Berberis repens* phase (PSME/BERE-BERE), Douglas-fir/creeping holly grape-creeping holly grape phase. | Central (Little Rocky Mountains only). |
| | Pseudotsuga menziesii/ *Juniperus scopulorum* h.t. (PSME/JUSC), Douglas-fir/ Rocky Mountain juniper phase. | Central (Missouri Breaks only). |
| | *Pseudotsuga menziesii/Muhlenbergia cuspidata* h.t. (PSME/ MUCU), Douglas-fir/plains muhly. | Central (Missouri Breaks only). |

Group Four consists of Douglas-fir habitat types where ponderosa pine usually occurs as a major seral or climax associate especially at lower elevations. Group Four stands may exist as fire-maintained ponderosa pine stands that develop Douglas-fir regeneration beneath the pine in the absence of disturbance. Douglas-fir is usually present in seral stands, but ponderosa pine often dominates. These habitat types are too droughty for most other conifer species. Some Group Four sites (PSME/FESC h.t.) extend to elevations above the cold limits of ponderosa pine. Where such situations exist, Douglas-fir dominates most states of succession. Except on the better sites, stands are usually quite open regardless of species composition.

Rocky Mountain juniper may be a minor climax species on PSME/AGSP h.t.'s, and occasionally limber pine may occur. Group Four stands are generally quite open, but dense stands or thickets can occur where fire has been excluded or where good seed years and favorable moisture conditions have followed fire. The understory is usually sparse because of lack of moisture. Major herbs include bluebunch wheatgrass, rough and Idaho fescue, pinegrass, arrowleaf balsam root, western gromwell, Plains muhly, junegrass, and spreading dogbane. The most prevalent shrubs are snowberry, kinnikinnick, white spiraea, common juniper, bitterbrush, chokecherry, and serviceberry.

## Forest Fuels

Downed woody fuel loads average between 5 and 10 tons/acre (1 and 2 kg/$m^2$) in this group. Fuel loads in the grassy habitats usually average less than in the shrubby habitats. Fuel loads of 15 to 20 tons/acre (3.4 to 4.5 kg/$m^2$) are not uncommon. Brown and See (1981) show a value of 13 tons/acre (2.9 kg/$m^2$) as the average downed woody load for Groups Three, Four, and Five combined (table 4).

Fuel conditions and associated fire hazard are usually determined by stand development that in turn is governed by fire history. This is illustrated by the two stands in figure 14. Both stands are about 100 years old (table 6) and both are on Douglas-fir/kinnikinnick h.t.'s (PSME/ARUV). Stand 40A (fig. 14A) has two times as much downed woody fuel and three times as much duff (table 6) as does stand 37A (fig. 14B).

Overall fire potential was rated low for stand 37A and meduim for stand 40A (Fischer 1981a). Although stand histories were not documented, onsite inspection indicated more frequent and more recent fire in stand 37A than in stand 40A.

Live fuels can be a significant factor in Group Four stands. Dense thickets of Douglas-fir regeneration may become established during fire-free periods. Overstories become susceptible to stand-destroying crown fire when such situations are allowed to develop in the understory.

A

B

*Figure 14.—Examples of Fire Group Four stand and fuel conditions near White Sulphur Springs, Mont., Lewis and Clark National Forest. Both stands are on a Douglas-fir/kinnikinnick h.t. Stand age, total fuel load, fuel load by size class, and duff depths are given in table 6.*

**Table 6.**—Fuel loading by size class and duff depth for Fire Group Four stands shown in figure 14 (source: Fischer 1981a)

| Stand number | Habitat type | Age | Duff depth | Size class (inches) 0-1/4 | 1/4-1 | 1-3 | 3-6 | 6-10 | 10-20 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *Years* | *Inches* | *Tons/acre* | | | | | | |
| 37A | PSME/ARUV | 112 | 1.1 | 0.3 | 1.9 | 2.9 | 2.3 | 2.5 | 3.3 | 13.2 |
| 40A | PSME/ARUV | 105 | 3.0 | 0.4 | 1.9 | 6.0 | 7.7 | 2.6 | 7.0 | 25.6 |

## Role of Fire

Fire in the Douglas-fir climax series habitat types of Group Four maintains grasslands, opens stands of Douglas-fir or of seral ponderosa pine, and prepares seedbeds (see Group Two). But there are additional effects (Davis and others 1980):

1. Frequent fires in seral stands can maintain a ponderosa pine "fire climax" condition by killing fire-susceptible Douglas-fir seedlings before they become established. In this role, fire frequency largely determines the stand composition.

2. Following a prolonged fire-free period, Douglas-fir regeneration becomes established beneath the canopy. A ground or surface fire that reaches a thicket of saplings and small poles can ascend into the overstory, killing or injuring adjacent mature trees through the vegetative "fuel ladder." Fuel ladders increase the potential destructiveness of a fire by providing access to the canopy. During periods of high fire danger, this can result in a stand-destroying crown fire.

Historic fire frequency in Group Four habitat types probably was not very different from that of Group Two—that is, 5 to 20 or more years between fires. Successful suppression of surface fires in open, fire-maintained stands over the last few decades has altered the sites toward a more flammable condition that has increased the fire potential.

## Generalized Forest Succession

The theoretical climax forest on Group Four habitats is an all-aged or multistoried Douglas-fir forest, as shown in figure 15 (subsequent numbers in this section refer to fig. 15). Such a forest is unlikely to be achieved because of the prolonged fire-free period necessary for its development. Most old-growth forests will be open stands with varying understories depending on the stand's fire history. A grass/forb community with shrubs and conifer seedlings becomes established following a severe stand-destroying fire (No. 1). Frequent fire during this stage can result in a fire-maintained grassland (No. 2). A light burn during the grass/forb/shrub stage can prepare a seedbed favorable to conifer seedlings but may be a minor factor where seedling establishment is not hindered by ground cover.

In the absence of fire, the grass/forb/shrub stage will give way to conifer seedlings. Except on those high elevation sites above its cold limits, ponderosa pine will dominate initially if it dominated the prefire stand. Douglas-fir seedlings will also be present. Variation in seed crops is a factor in regeneration. A poor seed year will often retard regeneration. A fire at this stage will revert the site to grass/forb (No. 3).

In the absence of fire, ponderosa pine and Douglas-fir saplings will develop. Species composition and density of stems

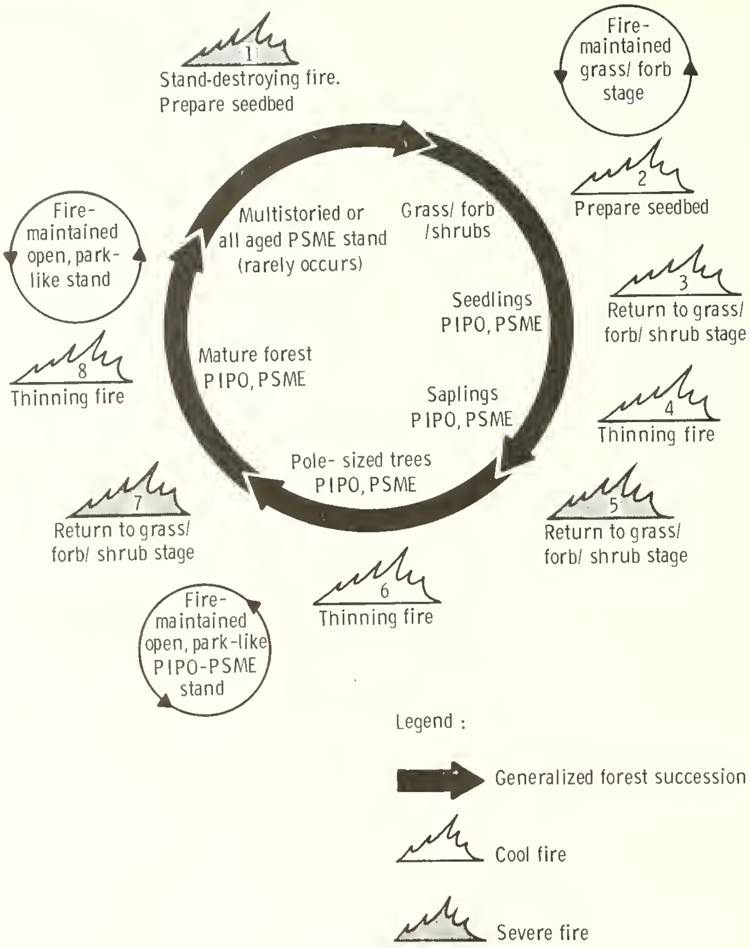



*Figure 15.—Generalized forest succession in Fire Group Four: warm, dry Douglas-fir habitat types.*

will depend on site conditions, length of the regeneration period, and how long fire has been absent. Not much ponderosa pine, for example, will be present if fire is absent for a prolonged period. A severe fire will return the site to the grass/forb/shrub stage (No. 5). A light to moderate severity fire will tend to thin out Douglas-fir saplings and badly suppressed ponderosa pine saplings (No. 4). A cool fire at this stage will also remove any recent seedlings.

The pole-sized tree stage can be represented by: (1) a rather open stand of Douglas-fir and ponderosa pine poles with a scattered seedlings and sapling understory, (2) a predominatly ponderosa pine or Douglas-fir pole stand with varying understory, or (3) a scattered pole stand with grass/forb/shrub understory. A light to moderately severe fire at this stage will thin the stand, removing understory vegetation and susceptible Douglas-fir stems (No. 6). Frequent fire will maintain an open, parklike stand of ponderosa pine on most Group Four habitats. A severe fire will revert the site to the grass/forb/shrub state (No. 7).

A mature forest of ponderosa pine, Douglas-fir, or a combination of the two, will eventually develop. Periodic fire at this stage will maintain the stand in an open, parklike condition (No. 8). Douglas-fir and some ponderosa pine regeneration may form in the understory of such stands during fire-free intervals. If fire is excluded for an unusually long period, the theoretical climax situation could develop.

## Successional Pathways

Hypothetical succession following fire and the absence of fire in this group is presented in figure 16 (subsequent states and numbers in this section refer to fig. 16). The elevation and geographic location of the site is a major determinant of species composition. Ponderosa pine will play a major role in plant succession on most Group Four sites. Some sites are, however, beyond the geographic range or above the cold limits of ponderosa pine. These sites will be dominated by Douglas-fir at all stages of development.

### SUCCESSION WITH PONDEROSA PINE

Frequent fire over long periods can maintain Group Four sites in a grass, forb, and shrub state (state A). In the absence of fire, ponderosa pine and Douglas-fir seedlings become established (state B). Any fire will probably kill these seedlings and maintain the grassy state (No. 1). Given a long enough fire-free interval, seedlings develop into saplings (state C). Many

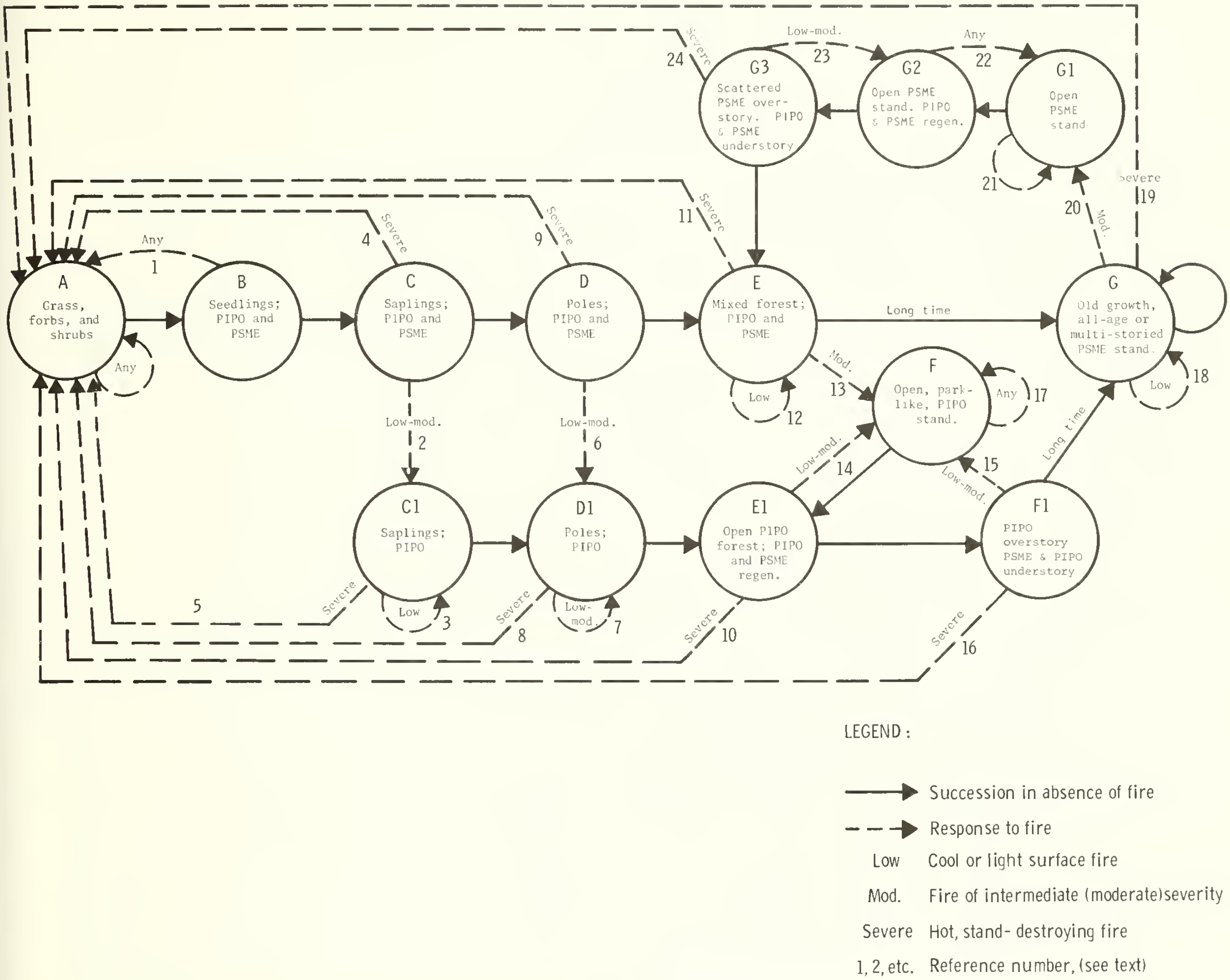



*Figure 16.—Hypothetical fire-related successional pathways for Fire Group Four habitat types.*

ponderosa pine saplings may survive a low to moderate fire (No. 2). This would result in a sapling stand devoid of Douglas-fir (state C1). A subsequent cool fire would have little impact on stand composition (No. 3), but a severe fire would revert the site to grass (No. 4).

If fire does not occur in the sapling state (state C), a ponderosa pine and Douglas-fir pole stand will develop (state D). Again, a severe fire may revert the site to grass (No. 5), and a low to moderately severe fire (No. 6) could result in the loss of Douglas-fir (state D1). Subsequent cool fires would merely affect undergrowth (No. 7). A severe fire would be unlikely because of lack of fuel, but if it did occur it could conceivably revert the stand to grass (No. 8).

A ponderosa pine/Douglas-fir pole stand (state D) will develop into a mixed species forest in the absence of fire (state E). The ponderosa pine pole stand (state D1) will develop into an open ponderosa pine forest (state E1). Both stands may have ponderosa pine and Douglas-fir regeneration in the understory. Both stands can also be destroyed by a severe fire (No. 10 and 11), although the open stand would be less susceptible to such a fate. A cool fire would thin out the understory of the mixed forest (No. 12), but a fire of moderate severity (No. 13) could kill the Douglas-fir while leaving enough pine to end up with an open, parklike ponderosa pine stand (state F). A light to moderately severe fire in states E1 and F1 would have the same effect (No. 14 and 15). A severe fire in state F1 could destroy the stand (No. 16).

Any fire occurring in state F would probably maintain the open, parklike condition (No. 17). During fire-free intervals, regeneration would likely develop (state E1) and succession would tend toward a two-storied stand (state F1). Unusually long fire-free periods would allow stands to develop toward a theoretical Douglas-fir climax condition (state G). Such a condition is rare. Stands tending toward the climax condition would not be seriously impacted by a cool fire (No. 18) and would probably be destroyed by a severe fire (No. 19). If the development toward the climax condition has progressed to the

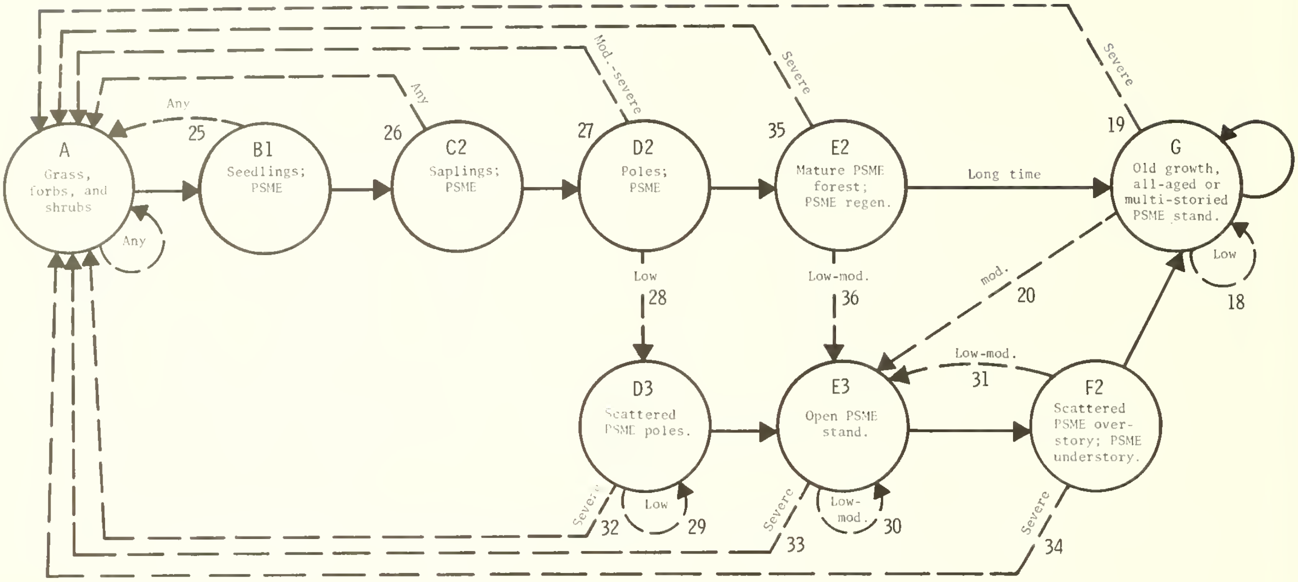



*Figure 16.—(con.)*

point where ponderosa pine has been eliminated from the stand, a fire of moderate severity (No. 20) could result in an open, parklike Douglas-fir stand (state G1). Such a stand could develop back to the mixed forest state (state E) in the absence of fire or be maintained in the open condition with frequent fire (No. 21, 22, and 23). If an understory does develop in the absence of fire (state G3), a severe stand destroying fire could occur and revert the site to grass (No. 24).

### SUCCESSION WITHOUT PONDEROSA PINE

Succession on Group Four sites located above the cold limits of ponderosa pine will be dominated by Douglas-fir. Succession will progress through a seedling, sapling, and pole stage (states B1, C2, and D2). Any fire during these stages will revert the site back to grass, forbs, and shrubs (No. 25, 26, and 27), except that some pole-sized Douglas-fir could survive a light burn (No. 28). A scattered pole stand (state D3) would result from such a situation. The scattered pole stand would develop into an open Douglas-fir stand (state E3), and then a two-storied stand (state F2) as seedlings become established and developed. Cool fires would tend to perpetuate the open condition (No. 29, 30, and 31), while severe fires would return the site to the grass/forb/shrub state (No. 32, 33, and 34).

If a fire does not occur during the pole stage (state D2), a Douglas-fir forest with a Douglas-fir understory will develop (state E2). A severe fire could destroy such a stand (No. 35), while a cool to moderately severe fire (No. 36) would remove the understory and perhaps thin the overstory leaving an open stand (state E3).

If fire is absent for an unusually long period, a climax forest could develop (state G). Such a forest would be affected by fire just as described for the habitats with ponderosa pine, except that ponderosa pine, of course, will be absent (states G, E3, and F2).

## Fire Management Considerations

Fire management considerations and opportunities for Group Four stands involve hazard reduction, seedbed preparation, control of species composition, safeguarding recreation sites, improving wildlife habitat, and enhancing esthetic values.

### WILDFIRE HAZARD REDUCTION

In the absence of fire, hazardous fuel situations often develop in Group Four stands. The combination of dense Douglas-fir (or ponderosa pine) understories, accumulated deadfall, decadent shrubs, and other accumulated litter and debris can produce fires severe enough to scorch the crowns and kill the cambium of overstory trees. Although they were developed in western larch/Douglas-fir forests (Fire Groups Five and Six), Norum's (1977) guidelines can be used to write fire prescriptions for safely reducing this hazard. Prescribed fire can also be used to reduce the hazard associated with logging slash resulting from clearcuts and partial cuts in Group Four stands. Most fire prescriptions can be written so as to accomplish silvicultural, range, and wildlife objectives as well as hazard reduction.

### SILVICULTURE

Where timber management is the objective, fire can be used to dispose of slash, prepare seedbeds, control species composition, and to reduce the probability of stand-destroying wildfires. Ponderosa pine is often a favored timber species on Group Four habitat types. It may, for example, be deemed desirable to maintain ponderosa pine dominance in stands where Douglas-fir is plagued with severe mistletoe or chronic budworm damage. Fire can be used to remove unwanted Douglas-fir regeneration once the ponderosa pine reaches about 5 inches (about 13 cm) in diameter. Wright (1978) recommends that there be an adequate number of trees 10 to 12 ft (3 to 3.7 m) tall before regular prescribed burning begins, although light surface fires will leave trees 6 to 8 ft (1.8 to 2.4 m) tall unharmed. Larger Douglas-fir trees will also survive most light surface fires; so there need be no concern about completely eliminating Douglas-fir from the stand. Where butt rot is common on overstory Douglas-fir, however, increased mortality should be expected.

### RANGE AND WILDLIFE HABITAT MANAGEMENT

Big game winter and spring range can be rejuvenated with properly applied prescribed fire, especially in the spring. Such fires can reduce encroachment by Douglas-fir, remove accumulated dead plant materials, recycle nutrients, regenerate mature and decadent shrubs, and increase distribution and production of nutrient-rich grasses, forbs, and legumes. Prescribed fire can be used to increase the nutritional value of critical wintering and fawning habitat, and thereby reduce neonatal fawn losses of mule deer (Schneegas and Bumstead 1977). Willms and others (1980) found that deer and cattle preferred forage from burned Douglas-fir/bluebunch wheatgrass communities over unburned control areas.

### RECREATION AND ESTHETICS

Prescribed fire can be used to fireproof the areas immediately adjoining campgrounds. Such treatment not only reduces fire hazard, but also improves viewing and travel from the campground to the surrounding forest.

## FIRE GROUP FIVE: COOL, DRY DOUGLAS-FIR HABITAT TYPES

| ADP code | Habitat type-phase (Pfister and others 1977) | Montana forest region (Arno 1979) |
|---|---|---|
| 220 | *Pseudotsuga menziesii/Festuca idahoensis* h.t. (PSME/FEID), Douglas-fir/Idaho fescue. | Southwestern and south-central. |
| 321 | *Pseudotsuga menziesii/Calamagrostis rubescens* h.t.-*Agropyron spicatum* phase (PSME/CARU-AGSP), Douglas-fir/pinegrass-bluebunch wheatgrass phase. | Central. |
| 330 | *Pseudotsuga menziessi/Carex geyeri* h.t. (PSME/CAGE), Douglas-fir/elk sedge. | Central, south-central and southwestern. |
| 370 | *Pseudotsuga menziesii/Arnica cordifolia* h.t. (PSME/ARCO), Douglas-fir/heartleaf arnica. | Central and southwestern. |
| 380 | *Pseudotsuga menziesii/Symporicarpos oreophilus* h.t. (PSME/SYOR), Douglas-fir/mountain snowberry. | Southwestern. |
| 461 | *Picea/Senecio streptanthifolius* h.t.-*Pseudotsuga menziesii* phase (PICEA/SEST-PSME), spruce/cleftleaf groundsel-Douglas-fir phase. | North-central, central, and southwestern. |

Fire Group Five habitat types support Douglas-fir stands even under the influence of periodic fire. Douglas-fir is the indicated climax species on all Group Five habitats except spruce/cleft-leaf groundsel. Douglas-fir dominates most Group Five seral communities and often is the only conifer present. Group Five sites are generally too dry for lodgepole pine and usually too cold for ponderosa pine. Rocky Mountain juniper, spruce, whitebark pine, lodgepole pine, limber pine, and subalpine fir may occur as accidental individuals, minor seral species, or minor climax species.

Regeneration is often difficult on these habitats. On north- and northeast-facing slopes, however, heavily overstocked stagnant stands often develop. Undergrowth may be sparse. Forbs often dominate the undergrowth, but grass and shrubs are usually present. Common undergrowth forbs include pussytoes, heart-leaf arnica, timber milkvetch, arrowleaf balsamroot, virgin's bower, strawberry, sweet cicely, pyrola, cleft-leaf groundsel, and western meadow rue. Common grasses include bluebunch wheatgrass, pinegrass, elk sedge, Idaho fescue, rough fescue, wheller bluegrass, and spike trisetum.

Group Five shrubs include big sagebrush, common juniper, wax current, russett buffaloberry, white spiraea, and mountain snowberry.

## Forest Fuels

Downed, dead fuel loads for this group average about 10 tons/acre (about 2 kg/m$^2$). Downed woody fuel loadings calculated by Brown and See (1981) are shown in table 4 and in figure 2.

While downed, dead woody fuel loadings are greater in Group Five than in the previous four groups, live fuels are less of a problem. Both undergrowth and regeneration are usually sparce in Group Five stands. This factor plus the usual open nature of the stands results in a low probability of crown fire. Individual trees will often have branches close to the ground (fig. 17). If sufficient fuels are available on the ground, torching can occur.

*Figure 17.—A Fire Group Five stand on a Douglas-fir/Idaho fescue h.t. This 100-year-old Douglas-fir stand on the Lewis and Clark National Forest has a total downed, dead fuel load of 6.6 tons/acre (1.5 kg/m$^2$). Material less than 3 inches (7.6 cm) in diameter accounts for 2.8 tons/acre (0.62 kg/m$^2$), and material more than 3 inches (7.6 cm) accounts for the remaining 3.8 tons/acre (0.85 kg/m$^2$). Duff depth is 0.9 inches (2.3 cm).*

## Role of Fire

The role of fire in Group Five is not well defined. Fire probably occurred less frequently than it did in ponderosa pine habitat types (Groups Two and Three) or in the warmer Douglas-fir habitat types (Group Four). The relatively light fuel loads, sparse undergrowth, and generally open nature of the stands would appear to favor long fire-free intervals. However, Arno and Gruell (1983) estimate a mean fire interval of 35 to 40 years in presettlement stands in southwestern Montana.

Fire probably played an important role in favoring ponderosa pine on PSME/CARU-AGSP sites. Without fire, ponderosa pine would be slowly replaced by Douglas-fir on these sites. Fire's role in seedbed preparation on most Group Five sites is confounded by the difficulty of regeneration to progress beyond the seedling stage on these droughty sites because of undergrowth and overstory competition. Where dense regeneration does occur, fire probably played a role as a thinning agent in sapling and pole-sized stands. Ground fire probably maintained many mature stands in an open, parklike condition. Many presettlement stands were actually scattered groves. Fire suppression has allowed these groves to become forest stands (Arno and Gruell 1983).

## Generalized Forest Succession

The generalized forest succession discussed here and illustrated in figure 18 assumes sites are above the cold limits of ponderosa pine. (On sites where ponderosa pine is a major seral species [PSME/CARU-AGSP] refer to figure 15 [Fire Group Four] and the associated discussion of "Generalized Forest Succession.")

Frequent fire could maintain Group Five sites as grassland, as shown in figure 18, No. 1 (subsequent numbers in this section refer to fig. 18). A fire in the grass/forb/shrub stage will prepare a seedbed (No. 2) for Douglas-fir seedlings. Seedling establishment is usually slow and probably requires favorable combination of adequate seedbed, adequate moisture, and abundant seed. When favorable conditions for seedling establishment do occur, an even-aged stand usually develops. Any fire in either the seedling stage or the sapling stage reverts the site to grass (No. 3).

A light surface fire in a pole-sized stand would thin out the more susceptible stems (No. 4). A severe fire in pole-sized stands (No. 5) would likely kill all trees and again revert the site to the grassy stage. A less than severe fire in a mature stand (No. 6) could act as an underburn and thin the stand and

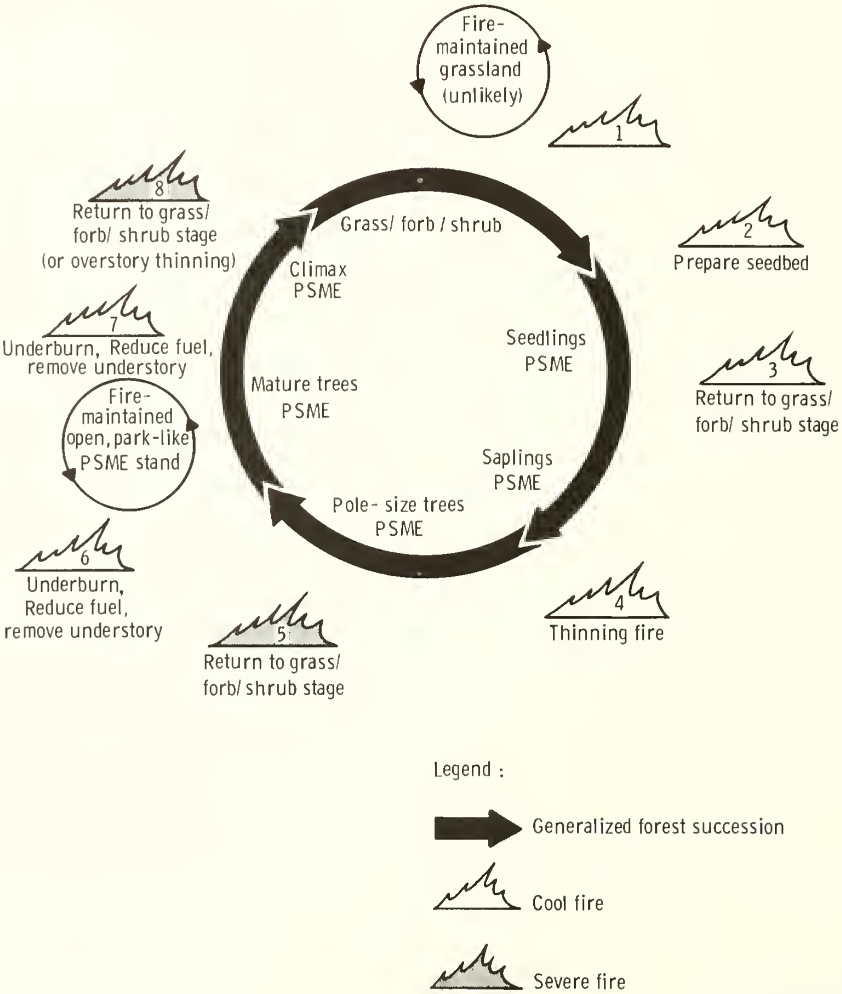



*Figure 18.—Generalized forest succession in Fire Group Five: cool, dry Douglas-fir habitat types.*

create an open stand condition. Subsequent light burns could maintain this open condition and result in a parklike Douglas-fir stand. If a stand escapes fire and nears the climax situation, it will likely have a Douglas-fir understory, sparse undergrowth, and moderate amounts of dead fuel on the forest floor. A light fire would remove the undergrowth and reduce dead woody fuel (No. 7). A severe fire in a climax or near climax stand would either destroy the stand and revert the site to the grass/forb/shrub state, or thin the overstory and leave an open, parklike stand (No. 8).

## Successional Pathways

Hypothetical succession following fire and the absence of fire on most Group Five habitat types is presented in figure 19 (subsequent states and numbers in this section refer to fig. 19). This discussion does not pertain to those Group Five sites on which ponderosa pine is a major seral component (PSME/CARU-AGSP). (Succession on those sites is more nearly that presented in fig. 16 and the associated discussion of "Successional Pathways" for Fire Group Four.)

State A is a grass, forb, and shrub mixture of varying composition depending on site. Any fire at this state will perpetuate the treeless condition (No. 1). In the absence of fire, Douglas-fir seedlings and saplings will develop on the site (state B). Development of this state is not well understood, as indicated in the previous discussion of the role of fire in Group Five habitat types. Any fire in the seedling or sapling state will usually return the site to a treeless condition (No. 2). Sufficient fuel for a fire during the seedling state would be unlikely.

Pole-sized Douglas-fir trees will develop in the absence of fire (state C). Pole stands may be dense on some north- and north-east-facing slopes, but these are not the common situation in this group. A moderate to severe fire will revert the pole stand to the grass/forb/shrub condition (No. 3). A light ground fire, however, will thin out the stand and leave scattered poles (No. 4). Subsequent light fire will have little impact on a scattered pole stand (No. 5) while a severe fire (unlikely because of insufficient fuel) could destroy the stand (No. 6). In the absence of severe fire, the scattered pole condition (state C1) will mature into an open, parklike Douglas-fir stand (state D1). Periodic light to moderate fire will perpetuate this condition (No. 7). Again, a severe fire could occur and destroy the stand (No. 8) if sufficient fuel is available.

If a pole stand (state C) escapes fire, a mature stand of Douglas-fir with a scattered Douglas-fir understory will develop (state D). A light fire (No. 9) reduces fuel, thins understory, and prepares seedbed. A severe fire will destroy the stand and revert the site to the grass/forb/shrub condition (No. 10). A moderate fire at this stage (No. 11) could thin the overstory and remove the understory, thereby resulting in an open, parklike stand (state D1).

In the absence of fire, a climax condition would develop (state E). This condition would be characterized by varying degrees of crown closure in the overstory and by an understory of several layers. A severe fire (No. 12) would likely destroy such a stand, while a low intensity fire (No. 13) would affect only the understory. A moderately severe fire (No. 14) would torch out overstory trees and leave an open, parklike condition (state D1). Most old-growth Douglas-fir stands on Group Five sites in eastern Montana tend more toward the open condition than otherwise.

## Fire Management Considerations

Opportunities for fire use may be limited in some Group Five stands because of normally sparse fuels. Where sufficient surface fuels exist, fire can be used to accomplish timber, range, and wildlife management objectives.

On those sites where ponderosa pine is a major seral component, fire can be used to favor it over Douglas-fir as discussed for Fire Group Four habitats.

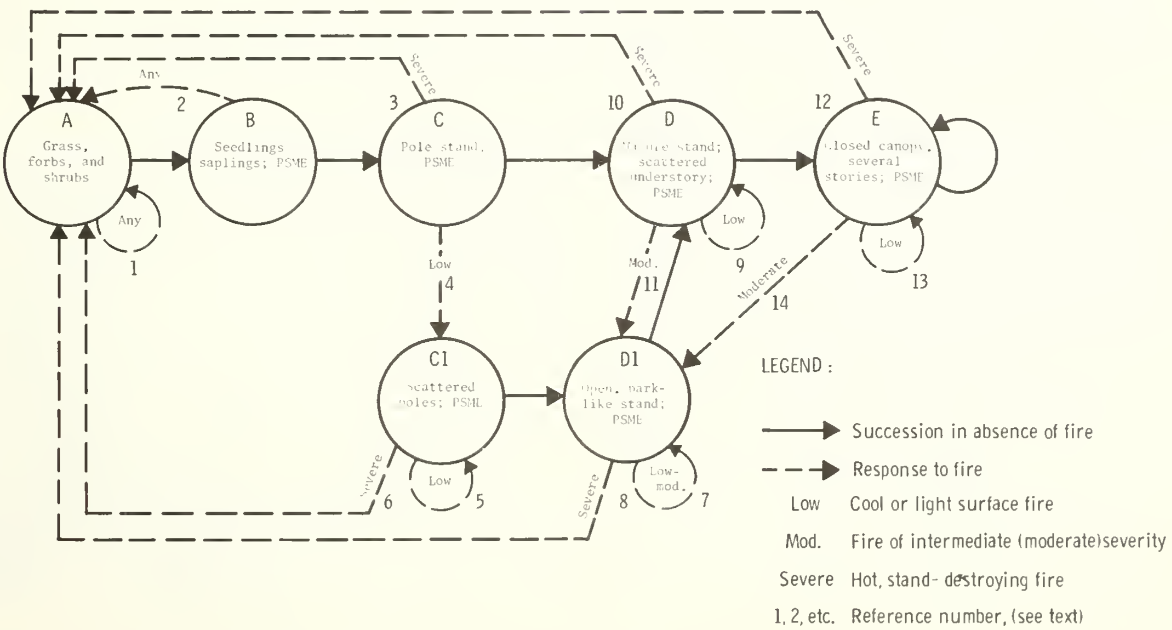



*Figure 19.—Hypothetical fire-related successional pathways for Fire Group Five habitat types.*

## HAZARD REDUCTION AND SITE PREPARATION

Fire can be used following timber harvest in Group Five stands to prepare seedbed and to reduce wildfire hazard from the harvest related slash. Care must be taken to control fire intensity when burning in partial-cut stands. The hazard reduction objective in such situations should be to remove the fine fuels only. Attempts to burn the larger slash could result in fire damage to the residual trees.

## FORAGE PRODUCTION

Periodic light surface fires in open canopy stands of mature trees can maintain parklike conditions and undergrowth species favorable to mule deer and domestic livestock. The use of fire for forage production may be difficult on some Group Five sites because the commonly sparse undergrowth will not carry fire. Caution should be used if timber milkvetch is present on grazed areas. This plant is poisonous to sheep and cattle and is highly resistant to damage by fire. It can send up shoots from the surviving taproot and set seed the first year following fire. If much mineral soil has been exposed, a good crop of seedlings are usually produced and the population of this species may greatly increase (McLean 1969).

# FIRE GROUP SIX: MOIST DOUGLAS-FIR HABITAT TYPES

| ADP code | Habitat type-phase (Pfister and others 1977, Roberts 1980) | Montana forest region (Arno 1979) |
|---|---|---|
| 261 | *Pseudotsuga menziesii/Physocarpus malvaceus* h.t.-*Physocarpus malvaceus* phase (PSME/PHMA-PHMA), Douglas-fir/ninebark-ninebark phase. | Central, southwestern, and south-central. |
| | Pseudotsuga menziesii/*Viola canadensis* h.t. (PSME/VICA), Douglas-fir/Canadian violet. | Central (Bearpaw Mountains only). |
| 281 | *Pseudotsuga menziesii/Vaccinium globulare* h.t.-*Vaccinium globulare* phase (PSME/VAGL-VAGL), Douglas-fir/blue huckleberry-blue huckleberry phase. | Central, southwestern, and south-central. |
| 282 | *Pseudotsuga menziesii/Vaccinium globulare* h.t.-*Arctostaphylos uva-ursi* phase (PSME/VAGL-ARUV), Douglas-fir/blue huckleberry-kinnikinnick phase. | Central. |
| 283 | *Pseudotsuga menziesii/Vaccinium globulare* h.t.-*Xerophyllum tenax* phase (PSMA/VAGL-XETE), Douglas-fir/blue huckleberry-beargrass phase. | Central. |
| | *Pseudotsuga menziesii/Linnaea borealis* h.t.-*Arctostaphylos uva-ursi* phase (PSME/LIBO-ARUV), Douglas-fir/twinflower-kinnikinnick phase. | Central (Little Rocky Mountains only). |
| 291 | *Pseudotsuga menziesii/Linnaea borealis* h.t.-*Symphoricarpos albus* phase (PSME/LIBO-SYAL), Douglas-fir/twinflower-snowberry phase. | Central. |
| 292 | *Pseudotsuga menziesii/Linnaea borealis* h.t.-*Calamagrostis rubescens* phase (PSME/LIBO-CARU), Douglas-fir/twinflower-pinegrass phase. | Central and southwestern. |
| 293 | *Pseudotsuga menziesii/Linnaea borealis* h.t.-*Vaccinium globulare* phase (PSME/LIBO-VAGL), Douglas-fir/twinflower-blue huckleberry phase. | Central. |
| 312 | *Pseudotsuga menziesii/Symphoricarpos albus* h.t.-*Calamagrostis rubescens* phase (PSME/SYAL-CARU), Douglas-fir/snowberry-pinegrass phase. | Central, southwestern, and south-central. |
| 313 | *Pseudotsuga menziesii/Symphoricarpos albus* h.t.-*Symphoricarpos albus* phase (PSME/SYAL-SYAL), Douglas-fir/snowberry-snowberry phase. | North-central, central, southwestern, and south-central. |
| | *Pseudotsuga menziesii/Amelanchier alnifolia* h.t. (PSME/AMAL), Douglas-fir/serviceberry. | Central (Bearpaw Mountains only). |
| 322 | *Pseudotsuga menziesii/Calamagrostis rubescens* h.t.-*Arctostaphylos uva-ursi* phase (PSME/CARU-ARUV), Douglas-fir/pinegrass-kinnikinnick phase. | Central. |
| 323 | *Pseudotsuga menziesii/Calamagrostis rubescens* h.t.-*Calamagrostis rubescens* phase (PSME/CARU-CARU), Douglas-fir/pinegrass-pinegrass phase. | North-central, central southwestern, and south-central. |
| 360 | *Pseudotsuga menziesii/Juniperus communis* h.t. (PSME/JUCO), Douglas-fir/common juniper. (Includes those stands on calcareous substrates. See Fire Group Seven for stands on granitic substrates.) | North-central, central, and southwestern. |

Fire Group Six habitat types occur throughout eastern Montana usually at elevations of about 4,800 ft to 7,200 ft (about 1 525 m to 2 135 m). Douglas-fir is both the indicated climax species and a vigorous member of seral communities. It is not uncommon for Douglas-fir to dominate all stages of succession on these sites. Lodgepole pine is a major seral component in many Group Six stands. Whitebark pine is usually well represented at upper levels on PSME/CARU-CARU sites, and limber pine is common on limestone substrates on PSME/PHMA-PHMA sites in the south-central region. Subalpine fir and spruce are essentially absent on the habitat types. Ponderosa pine will occur at low elevations, but it is not a major component.

Shrubs and moist site forbs dominate the undergrowth along with pinegrass, beargrass, and elk sedge. Common shrubs include ninebark, snowberry, white spiraea, oceanspray, blue huckleberry, grouse whortleberry, kinnikinnick, twinflower, and common juniper. Forbs include sweet cicely, fairy bells, starry Solomon's seal, western meadow rue, heartleaf arnica, and mountain arnica. Undergrowth composition will vary by habitat type and phase.

## Forest Fuels

Downed dead fuel loads in Group Six stands average about 13 tons/acre (about 3 $kg/m^2$) but can be much heavier. Fuel conditions will vary according to stand density and species composition. The most hazardous conditions occur in well-stocked stands with dense Douglas-fir understories (fig. 20). These stands are usually characterized by relatively large amounts of downed twigs and small branchwood less than 3 inches (7.62 cm) in diameter (table 7) beneath partially fallen and standing dead sapling and small pole-sized stems.

The absence of dense understories results in reduced fire hazard (fig. 21). However, the density of overstory trees and the presence of dead branches near ground level create a crown fire potential under severe burning conditions.

Fuel conditions in the stands dominated by lodgepole pine tend to be less hazardous than in stands dominated by Douglas-fir (fig. 22). Ladder fuels are much less prevalent, so the probability of fire going from the forest floor to the crowns is not as great.

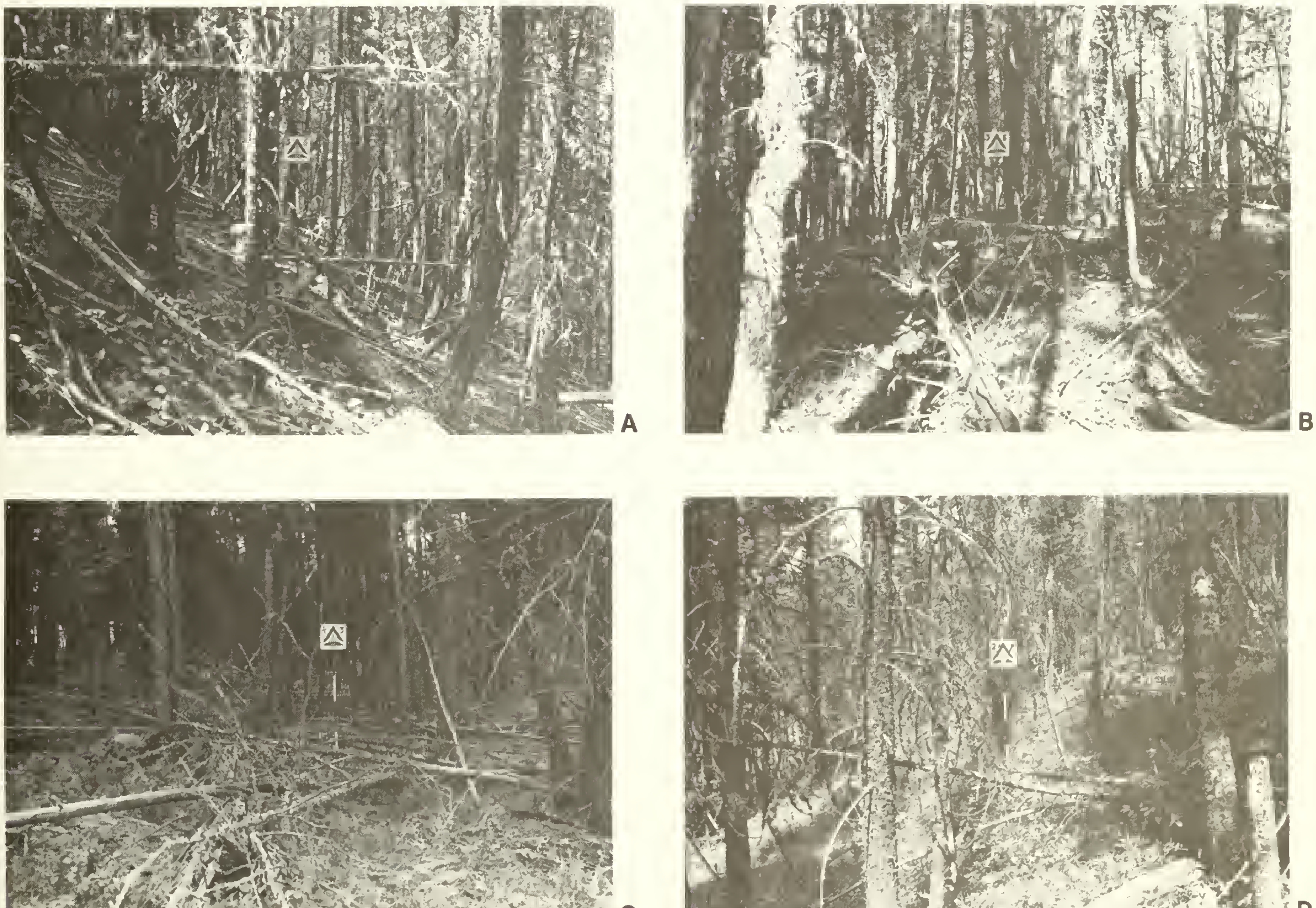



*Figure 20.—Examples of high-hazard fuel conditions in Fire Group Six Douglas-fir stands. Stands 36A, 38A, and 43A (A, B, and C) are on the Lewis and Clark National Forest near White Sulphur Springs, Mont. Stand 27A (D) is near Lincoln, Mont., Helena National Forest. Stand descriptions and fuel loadings are given in table 7.*

Table 7.—Fuel loading by size class and duff depth for Fire Group Six stands shown in figures 20, 21, and 22 (source: Fischer 1981a)

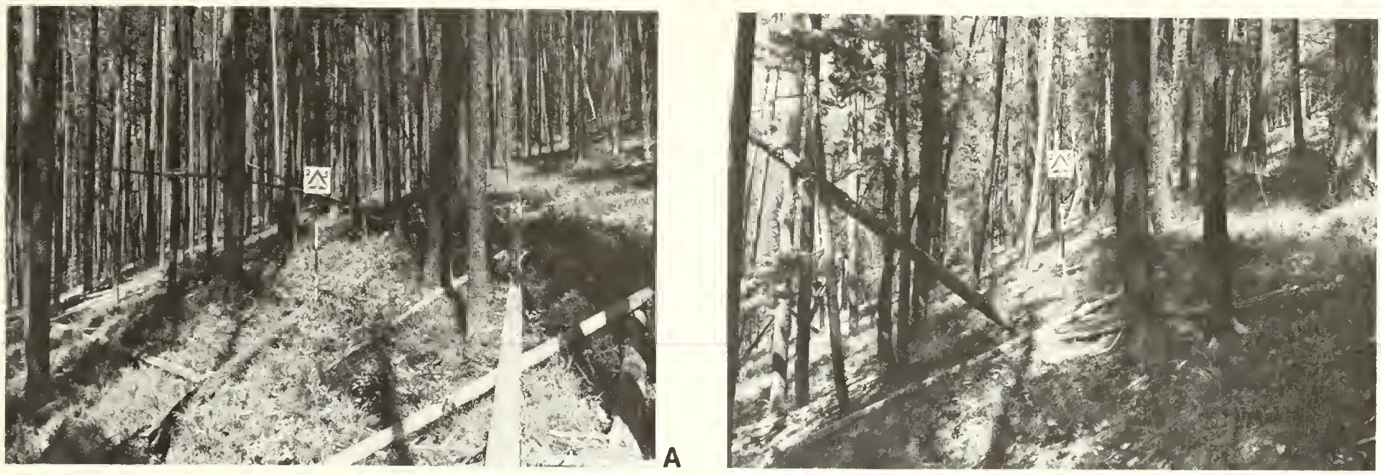
| Stand number | Habitat type | Age | Duff depth | Size class (inches) 0-1/4 | 1/4-1 | 1-3 | 3-6 | 6-10 | 10-20 | 20 + | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Years* | *Inches* | *Tons per acre* | | | | | | | |
| 26A | PSME/VAGL-XETE | 150 | 0.7 | 0.2 | 0.4 | 0.7 | 1.9 | 0.8 | 0 | 0 | 4.0 |
| 39A | PSME/SYAL-CARU | 75 | 1.4 | 0.4 | 0.7 | 1.3 | 1.4 | 2.5 | 0 | 0 | 6.3 |
| 28A | PSME/CARU-CARU | 77 | 2.4 | 0.4 | 1.1 | 3.6 | 2.0 | 0.8 | 0.4 | 0 | 8.3 |
| 36A | PSME/LIBO-CARU | 109 | 2.8 | 0.5 | 1.5 | 4.2 | 2.3 | 1.9 | 0 | 0 | 10.4 |
| 27A | PSME/VAGL-XETE | 86 | 1.9 | 0.2 | 0.8 | 1.2 | 1.9 | 5.2 | 1.7 | 0 | 11.0 |
| 25A | PSME/VAGL-XETE | 120 | 1.0 | 0.2 | 0.8 | 3.7 | 6.7 | 1.4 | 0 | 0 | 12.8 |
| 42A | PSME/CARU-CARU | 82 | 2.1 | 0.5 | 1.0 | 0.8 | 1.7 | 6.2 | 3.1 | 0 | 13.3 |
| 38A | PSME/CARU-CARU | 104 | 2.0 | 0.4 | 2.4 | 5.0 | 3.4 | 2.6 | 2.0 | 0 | 15.8 |
| 43A | PSME/SYAL-CARU | 92 | 2.7 | 0.5 | 2.7 | 8.7 | 3.6 | 1.8 | 0 | 0 | 17.3 |

A

B

C

*Figure 21.—Examples of moderate hazard fuel conditions in Fire Group Six Douglas-fir stands in eastern Montana. Stands 39A and 42A (A and B) are near White Sulphur Springs, Mont., Lewis and Clark National Forest. Stand 28A (C) is on the Helena National Forest near Lincoln, Mont. Stand descriptions and fuel loadings are given in table 7.*



A B

*Figure 22.—Examples of Fire Group Six lodgepole pine stands on the Helena National Forest near Lincoln, Mont. Stand descriptions and fuel loadings are given in table 7.*

The tendency toward overstocking and the development of dense understories are main reasons for high-hazard fuel conditions in many Group Six stands. Suppression mortality, snow breakage, blowdown, and insect and disease mortality operate at a high level in many stands. Relatively deep duff develops and contains a lot of rotten logs. Fires often sit and smolder undetected in the duff until burning conditions become favorable for fire spread.

## Role of Fire

Fire history studies conducted in Fire Group Six (PSME/CARU) stands in southeastern Montana indicate a mean fire interval of 42 years for presettlement stands (Arno and Gruell 1983).

Fire was important as a thinning agent and as a stand replacement agent. Low to moderate severity fires converted dense pole-sized or larger stands to a fairly open conditon. Subsequent light burning maintained stands in a parklike condition. Severe fires probably occurred in dense, fuel-heavy stands and resulted in stand replacement. Fire's role as a seedbed-preparing agent is less important in Group Six than in previously discussed fire groups.

Fire has a demonstrable effect on wildlife habitat in Group Six through its effects on food plants. The combination of opening up stands by killing overstory trees, reducing competition by removing understories, and rejuvenating sprouting plants through top kill, can significantly increase the availability of palatable browse and forage.

Fire's role as a stand replacement agent becomes more pronounced when the natural fire-free interval is increased through fire suppression, unless corresponding fuel reduction occurs.

## Generalized Forest Succession

The theoretical climax condition on Group Six sites is a multistoried Douglas-fir stand, although a fire-maintained open forest condition was the normal situation during the presettlement period, as shown in figure 23 (subsequent numbers in this section refer to fig. 23). Following a severe, stand-destroying fire (No. 1), grass forbs and shrubs dominate the site. Subsequent fires in this stage perpetuate grass, forbs, and shrubs (No. 2). Douglas-fir seedlings become established on most sites in the absence of fire. Lodgepole pine may also become established or even dominate the seedling stage if a seed source is available or if lodgepole was present in the previous stand.

A fire in the seedling stage (No. 3) will return the site to grass, forbs, and shrubs. Similarly, a fire in the sapling and pole stage (No. 4 and 5) will revert the site to the herbaceous condition.

A severe fire in the pole stage (No. 5) will either revert the site to grass, forbs, and shrubs, or if serotinous cone bearing lodgepole pine are present, the fire will help establish a lodgepole pine stand. A light fire (No. 6) in a large-diameter pole stand or a small-sawtimber-sized stand would thin out Douglas-fir and leave an open, parklike stand.

A severe fire in older stands (No. 7) will revert the site to grass, forbs, and shrubs. A low to moderately severe fire (No. 8) will often result in an open, parklike Douglas-fir stand.

## Successional Pathways

Group Six habitat types tend to support either mixed stands of Douglas-fir and lodgepole pine or nearly pure stands of Douglas-fir. These two major successional pathways are indicated in figure 24 (subsequent states and numbers in this section refer to fig. 24).

### DOUGLAS-FIR SITES

Starting with the site dominated by grass, forbs, and shrubs (state A), Douglas-fir seedlings and then saplings (state B1) eventually take over the site. Any fire will destroy the tree regeneration and allow herbaceous plants to again dominate (No. 1). In the absence of fire, a generally overstocked pole stand will develop (state C1). Depending on density of stems, a moderate to severe fire will revert the site to the herbaceous state (No. 2). A light to moderate surface fire (No. 3) may merely thin the stand, leaving scattered pole-sized trees on the site (state C2).

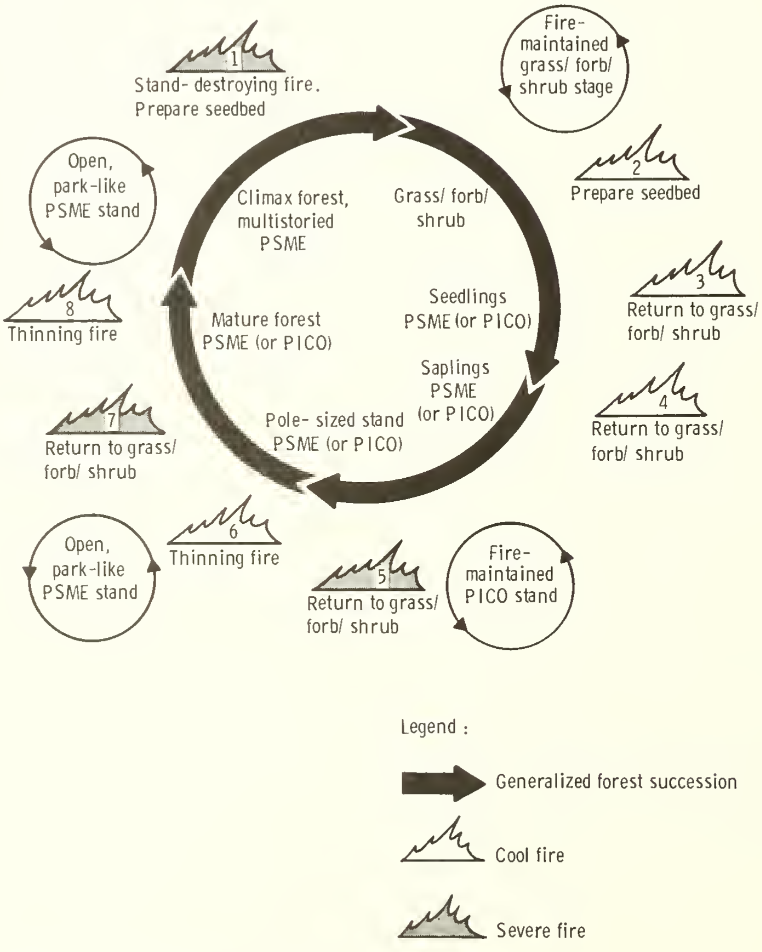



*Figure 23.—Generalized forest succession in Fire Group Six: moist Douglas-fir habitat types.*

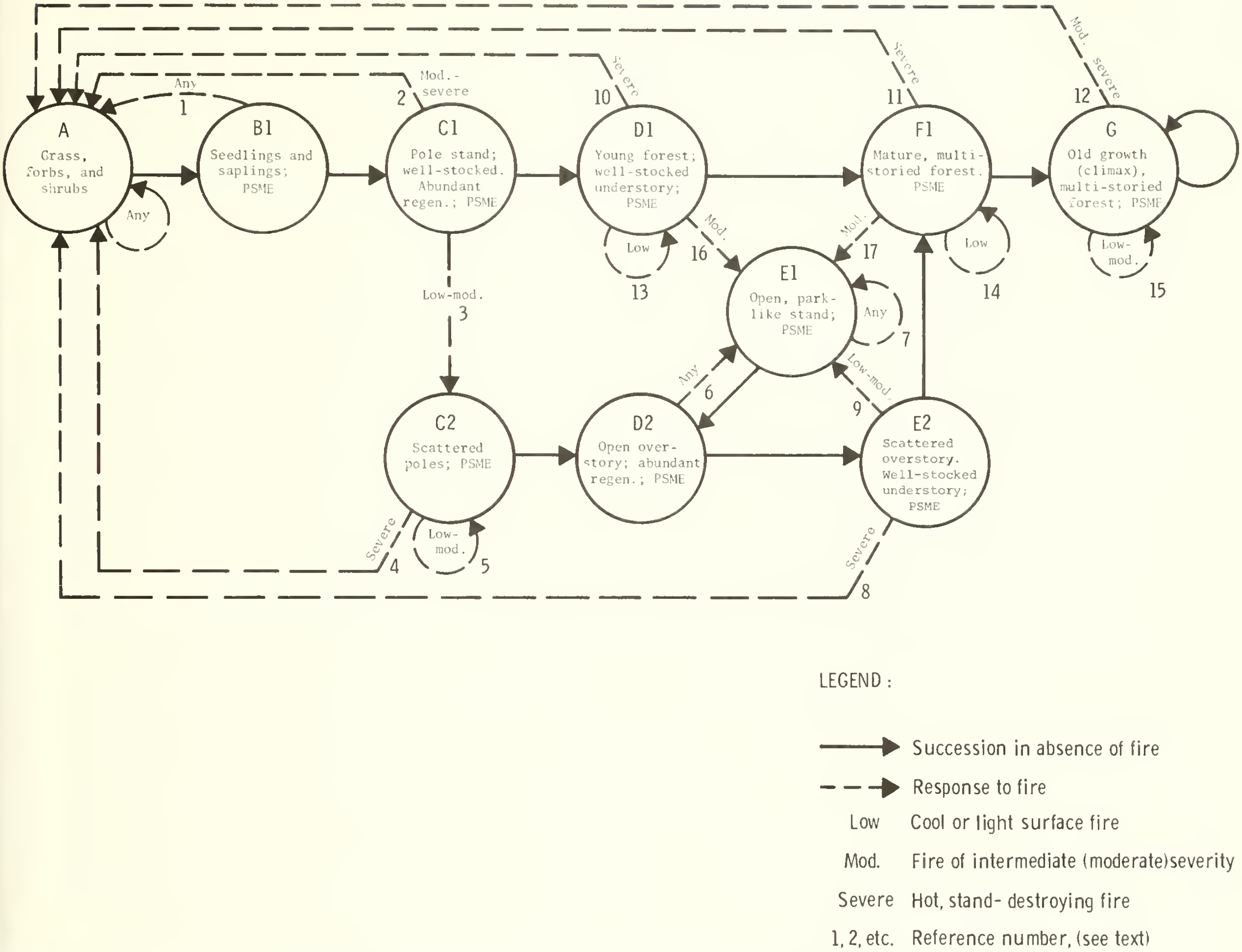



*Figure 24.—Hypothetical fire-related successional pathways for Fire Group Six habitat types.*

A subsequent severe fire (No. 4) is unlikely in state C2 because of the probable lack of fuel and distance between stems. If one did occur, the site would revert to grass, forbs, and shrubs. A low to moderate severity fire (No. 5) would maintain an herbaceous undergrowth beneath the scattered poles. In the absence of fire, an open overstory with Douglas-fir regeneration will develop (state D2). Any fire in this state (No. 6) would result in an open, parklike stand (state E1) that would be maintained by subsequent fires (No. 7). The absence of fire will allow the development of a well-stocked Douglas-fir stand beneath the scattered overstory trees (state E2). Such a stand would be susceptible to destruction by a severe fire (No. 8), while a low to moderately severe fire (No. 9) would result in the open, parklike condition (state E1). The absence of fire would allow the development of a mature Douglas-fir forest (state F1).

If fire fails to occur in the well-stocked pole state (state C1), a young Douglas-fir forest with a Douglas-fir understory will develop (state D1). Subsequent fire-free development will result first in a mature forest (state F1) and eventually in the climax situation (state G). Severe fires in any of these states will likely result in stand destruction (No. 10, 11, and 12). Moderate severity fires (No. 16 and 17) may result in the open, parklike condition (state E1). Low severity fire will have little effect on these stands (No. 13, 14, and 15).

## DOUGLAS-FIR/LODGEPOLE PINE SITES

On Group Six sites that will support lodgepole pine as well as Douglas-fir, succession in the absence of fire is similar to that described for Douglas-fir sites, except that lodgepole pine is usually a major component of seral stands. Fire-free succession progresses from the herbaceous state (state A) to a mixed species seedling and sapling state, a pole-sized tree state, a young forest state, the mature forest, and eventually the climax forest (states B2, C3, D3, F2, and G respectively). Any fire in the seedling/sapling state (No. 18) reverts the site to the herbaceous condition (state A). Severe fires in states C3, D3, F2, and G have a similar result (No. 19, 20, 21, and 12). Light surface fires in young and mature forests (states D3 and F2) have little effect on succession (No. 22 and 23).

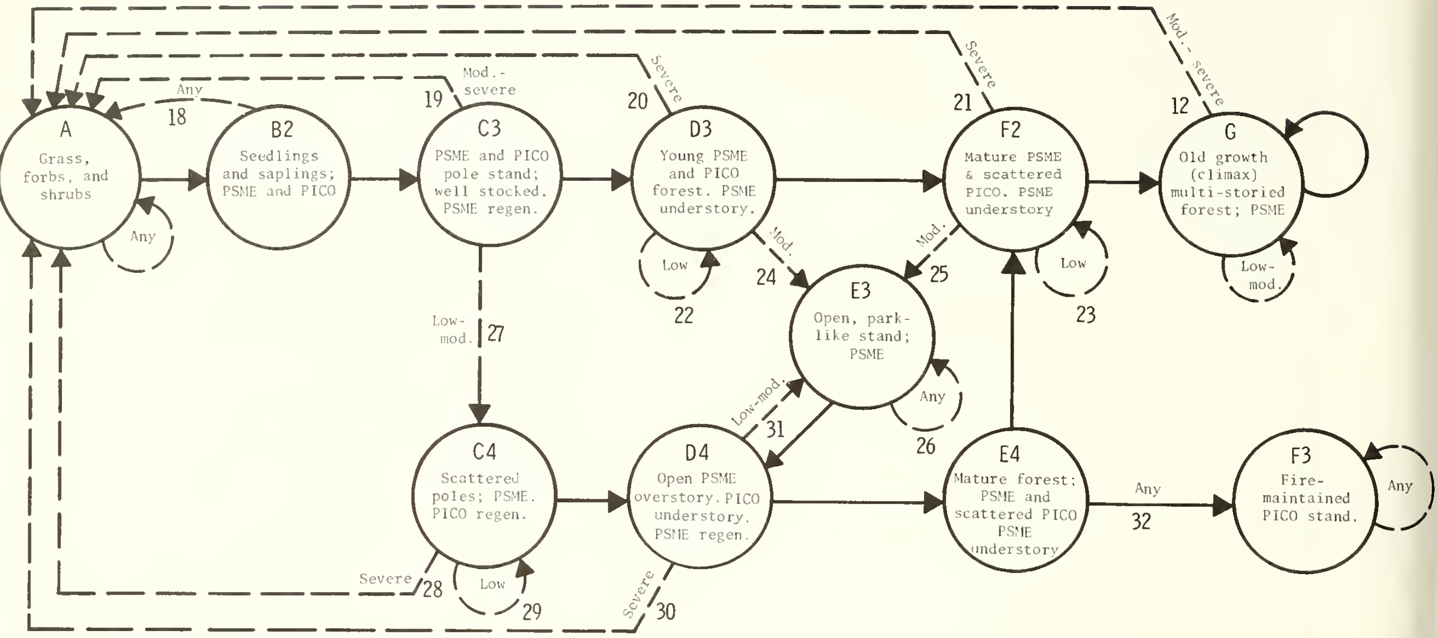



*Figure 24.—(con.)*

Moderately severe fires in these two states (No. 24 and 25) favor the more fire-resistant Douglas-fir trees over the lodgepole pines and can result in an open, parklike Douglas-fir stand or Douglas-fir/lodgepole pine stand (state E3) which will be maintained by subsequent fires (No. 26).

A low to moderately severe fire (No. 27) in the mixed-species pole state (state C3) can result in scattered Douglas-fir poles with abundant lodgepole pine regeneration (state C4), assuming that the burned lodgepole pine have serotinous cones. Lack of fuel would probably preclude a stand-destroying fire in this state (No. 28), and light surface fire would probably have minimal impact (No. 29). In the absence of fire, a lodgepole pine stand would develop beneath the scattered Douglas-fir overstory (state D4). Such a stand would be susceptible to destruction by a severe fire (No. 30). A cool to moderately severe fire could destroy the lodgepole pine understory (No. 31) and result in an open, parklike Douglas-fir stand (state E3). Subsequent fire would maintain this condition (No. 26), but the lack of fire would allow a lodgepole pine and Douglas-fir understory to develop (state D4). Continued lack of fire would allow the development of a mature lodgepole pine stand with a Douglas-fir understory (state E4). Subsequent fire (No. 32) can result in a fire-maintained lodgepole pine stand (state F3), while lack of fire allows a mature Douglas-fir forest to develop (state F2).

## Fire Management Considerations

Fire Group Six stands are quite variable depending on site conditions, stand history, and successional stage. Fire management considerations must, therefore, be attuned to this variation.

### WILDFIRE SUPPRESSION

Protection from unwanted fire may be a major fire management consideration in those stands where combinations of live and dead fuels result in a severe fire behavior potential. It may be difficult and impractical to abate the fire hazard in such stands except in conjunction with timber harvest operations. Preattack planning coupled with rapid detection and initial attack may be the only reasonable means to deal with such situations until such time as harvest operations can be scheduled.

### HAZARD REDUCTION AND SITE PREPARATION

Fire can be used to prepare seedbeds and reduce hazard following logging. Care must be taken to control fire intensity when burning in partial cut stands. The diameter of residual Douglas-fir trees and their branching habit will dictate, to a large extent, the kind of fire that can be prescribed. Guidelines for fuel consumption and duff reduction developed for western Montana Group Six stands should be consulted (Norum 1977 and DeByle 1981).

### FORAGE PRODUCTION

Fire can be used to enhance and maintain favorable forage for livestock and big game in open Douglas-fir stands. Periodic light fire will stimulate production of grass, forbs, and sprouting shrubs on many Group Six habitats.

## FIRE GROUP SEVEN: COOL HABITAT TYPES USUALLY DOMINATED BY LODGEPOLE PINE

| ADP code | Habitat type-phase | Montana forest region |
|---|---|---|
| | (Pfister and others 1977, Roberts 1980) | (Arno 1979) |
| 360 | *Pseudotsuga menziesii/Juniperus communis* h.t. (PSME/JUCO), Douglas fir/common juniper. (Includes those stands on granitic substrates. See Fire Group Six for stands on calcarious substrates.) | North-central, central, and southwestern. |
| 250 | *Pseudotsuga menziesii/Vaccinium caespitosum* h.t. (PSME/VACA), Douglas-fir/dwarf huckleberry. | North-central and central. |
| | Pseudotsuga menziesii/*Cornus canadensis* h.t.-*Linnaea borealis* phase (PSME/COCA-LIBO), Douglas-fir/bunchberry dogwood-twinflower phase. | Central (Bearpaw Mountains only). |
| | *Pseudotsuga menziesii/Cornus canadensis* h.t.-*Vaccinium myrtillus* phase (PSME/COCA-VAMY), Douglas-fir/bunchberry dogwood-myrtle whortleberry phase. | Central (Bearpaw Mountains only). |
| 450 | *Picea/Vaccinium caespitosum* h.t. (PICEA/VACA), spruce/dwarf huckleberry. | North-central. |
| 470 | *Picea/Linnaea borealis* h.t. (PICEA/LIBO), spruce/twinflower. | Central, south-central, and southwestern. |
| 640 | *Abies lasiocarpa/Vaccinium caespitosum* h.t. (ABLA/VACA), subalpine fir/dwarf huckleberry. | Central and southwestern. |
| 654 | *Abies lasiocarpa/Calamagrostis canadensis* h.t.-*Vaccinium caespitosum* phase (ABLA/CACA-VACA), subalpine fir/bluejoint-dwarf huckleberry phase. | Central and southwestern. |
| 663 | *Abies lasiocarpa/Linnaea borealis* h.t.-*Vaccinium scoparium* phase (ABLA/LIBO-VASC), subalpine fir/twinflower-grouse whortleberry phase. | North-central, central, south-central, and southwestern. |
| 692 | *Abies lasiocarpa/Xerophyllum tenax* h.t.-*Vaccinium scoparium* phase (ABLA/XETE-VASC), subalpine fir/beargrass-grouse whortleberry phase. | North-central and southwestern. |
| 720 | *Abies lasiocarpa/Vaccinium globulare* h.t. (ABLA/VAGL), subalpine fir/blue huckleberry. | Central, south-central, and southwestern. |
| 731 | *Abies lasiocarpa/Vaccinium scoparium* h.t.-*Calamagrostis rubescens* phase (ABLA/VASC-CARU), subalpine fir/grouse whortleberry-pinegrass phase. | Central, south-central, and southwestern. |
| 732 | *Abies lasiocarpa/Vaccinium scoparium* h.t.-*Vaccinium scoparium* phase (ABLA/VASC-VASC), subalpine fir/grouse whortleberry-grouse whortleberry phase. | Central, south-central, and southwestern. |
| 791 | *Abies lasiocarpa/Carex geyeri* h.t.-*Carex geyeri* phase (ABLA/CAGE-CAGE), subalpine fir/elk sedge-elk sedge phase. | North-central and southwestern. |
| 910 | *Pinus contorta/Purshia tridentata* h.t. (PICO/PUTR), lodgepole pine/bitterbrush. | South-central. |
| 920 | *Pinus contorta/Vaccinium caespitosum* h.t. (PICO/VACA), lodgepole pine/dwarf huckleberry. | North-central, central, and southwestern. |
| 930 | *Pinus contorta/Linnaea borealis* c.t. (PICO/LIBO), lodgepole pine/twinflower. | Central, south-central, and southwestern (including Little Rocky Mountains). |
| 940 | *Pinus contorta/Vaccinium scoparium* c.t. (PICO/VASC), lodgepole pine/grouse whortleberry. | Central, south-central, and southwestern. |
| 950 | *Pinus contorta/Calamagrostis rubescens* c.t. (PICO/CARU), lodgepole pine/pinegrass. | Central, south-central, and southwestern. |
| | *Pinus contorta/Juniperus communis* h.t. (PICO/JUCO), lodgepole pine/common juniper. | Central (Little Rocky Mountains only). |

Fire Group Seven contains two groups of habitat types. The first group consists of lodgepole pine climax series habitat types (and community types) that support essentially pure stands of lodgepole pine. There is insufficient evidence to indicate that other species constitute the potential climax on these sites. The other group consists of those Douglas-fir, spruce, and subalpine fir habitat types that, regardless of potential climax species, are usually found in nature supporting lodgepole pine-dominated stands. Apparently, these stands seldom reach a near-climax condition. Periodic wildfires seem to recycle the stands before a substantial amount of mature lodgepole pine dies out.

Subalpine fir, spruce, Douglas-fir, and whitebark pine occur in varying amounts with lodgepole pine on most Group Seven habitat types. They are, however, less likely to be found on the lodgepole pine habitat types than on the others.

Undergrowth in Group Seven stands often consists of dense mats or layers of grasses or shrubs. The most common graminoid species are pinegrass, bluejoint, and elk sedge. Common shrubs include grouse whortleberry, blue huckleberry, dwarf huckleberry, myrtle whortleberry, twinflower, kinnikinnick, white spiraea, bunchberry dogwood, snowberry, common juniper, bitterbrush, buffaloberry, and creeping Oregon grape. Heartleaf arnica, broadleaf arnica, and western meadow rue are among the more common Group Seven forbs.

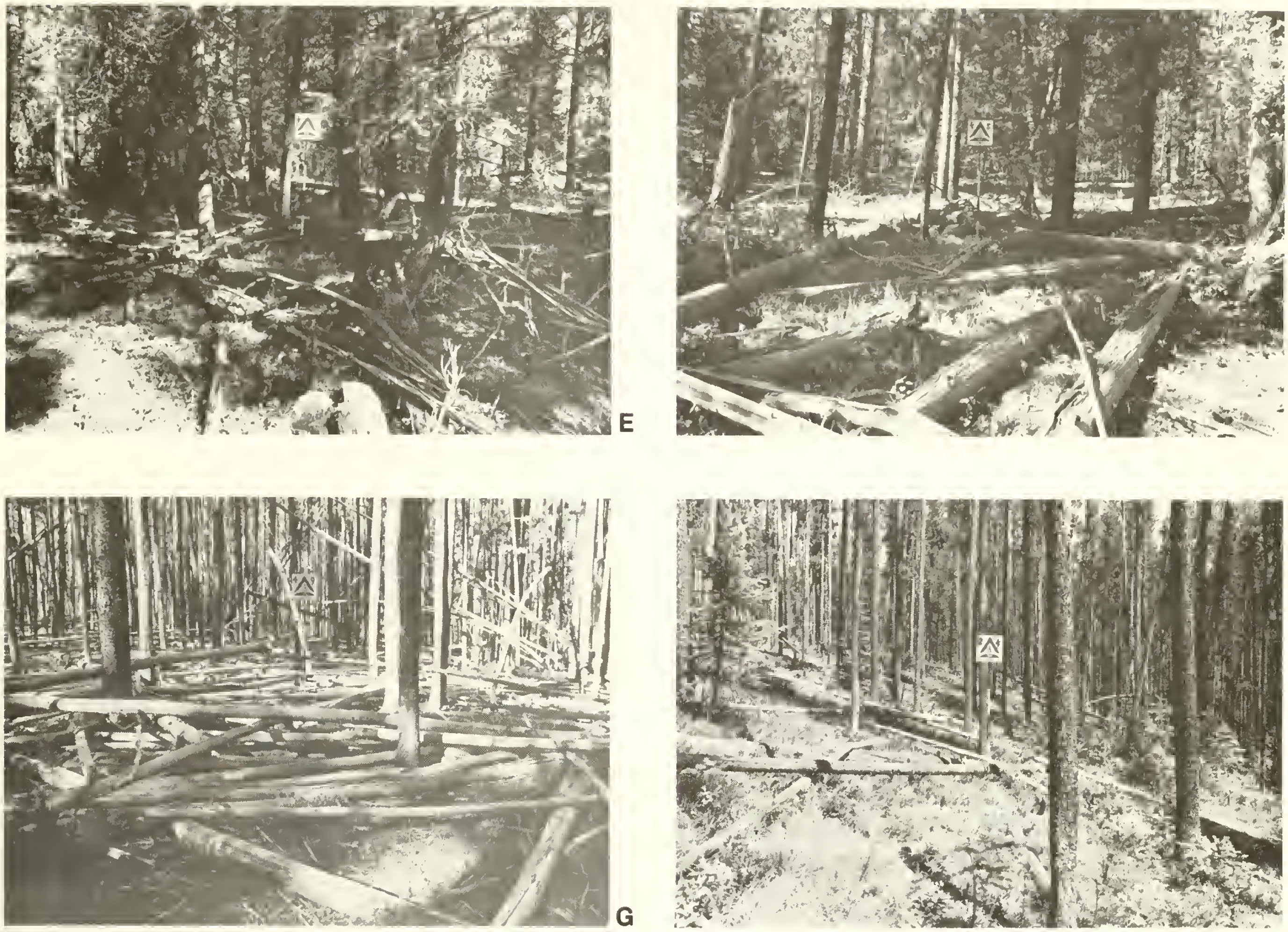
## Forest Fuels

The average downed, dead woody fuel load for Group Seven habitat types is about 15 tons/acre (about 3.4 kg/m$^2$), but maximum loads may greatly exceed this value. Group Seven fuel loads are characterized by relatively large amounts of material 3 inches (7.6 cm) or more in diameter. At least half the total weight is usually contributed by large material. As a general rule, the proportion of the total fuel load made up of material 3 inches or more in diameter increases as the total load increases. Brown and See (1981) show an average downed woody fuel load of 19 tons/acre (4.3 kg/m$^2$) for Fire Groups Seven and Eight combined (table 4 and fig. 2).

Live fuels can be a problem in Group Seven but not to the extent they are in some other fire groups. The primary live fuel consideration is related to the occurrence of dense patches or entire stands of young lodgepole with intermingled crowns and lower branches extending down to the surface fuels. When ignited under favorable burning conditions, such stands are usually destroyed in a few minutes.

Many mature stands are characterized by densely stocked, clean-boled trees with large amounts of deadfall on the forest floor (fig. 25 and table 8). An immediate source of deadfall in a young lodgepole stand is the snags created by the previous fire. Lyon (1977) found that after 2 years with little windthrow, lodgepole pine snags on the Sleeping Child Burn (Bitterroot National Forest) fell at an annual rate of 13.4 percent (fig. 26).


*Figure 25.—Examples of Fire Group Seven fuel conditions on eastern Montana National Forests. Stands 34A and 35A (A and B) are on White Sulphur Springs Ranger District, Lewis and Clark National Forest. Stands 45A, 46A, 47A, 48A, and 49A (C, D, E, F, and G) are on Philipsburg Ranger District, Deerlodge National Forest. Stand 24A (H) is on Lincoln Ranger District, Helena National Forest. Duff and fuel loading and other stand information is in table 8. (Source: Fischer 1981b.)*



E F G H

*Figure 25.—(con.)*

**Table 8.**—Fuel loading by size class and duff depth for Fire Group Seven stands shown in figure 25 (source: Fischer 1981b)

| Stand number | Habitat type phase | Age | Duff depth | Size class (inches) | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0-1/4 | 1/4-1 | 1-3 | 3-6 | 6-10 | 10-20 | |
| | | *Years* | *Inches* | *Tons per acre* | | | | | | |
| 35A | ABLA/VAGL | 123 | 2.4 | 0.3 | 1.2 | 5.1 | 4.3 | 1.1 | 0 | 12.0 |
| 24A | ABLA/XETE-VASC | 140 | 0.8 | 0.3 | 1.0 | 2.5 | 7.7 | 1.3 | 0 | 12.8 |
| 34A | PICO/VASC | 85 | 1.9 | 0.4 | 1.9 | 8.5 | 2.1 | 0.2 | 0 | 13.1 |
| 45A | PSME/VACA | 51 | 1.5 | 0.2 | 0.8 | 1.7 | 1.2 | 6.5 | 2.8 | 13.2 |
| 47A | PSME/VACA | 180 | 2.5 | 0.1 | 1.0 | 3.3 | 3.3 | 5.4 | 4.0 | 17.1 |
| 49A | ABLA/VACA | 162 | 2.3 | 0.3 | 1.4 | 8.1 | 11.8 | 1.0 | 0 | 22.6 |
| 48A | PSME/VACA | 130 | 2.2 | 0.2 | 1.0 | 1.2 | 4.2 | 14.9 | 10.2 | 31.7 |
| 46A | PSME/VACA | 55 | 2.5 | 0.2 | 0.7 | 1.2 | 10.7 | 17.0 | 2.5 | 32.3 |

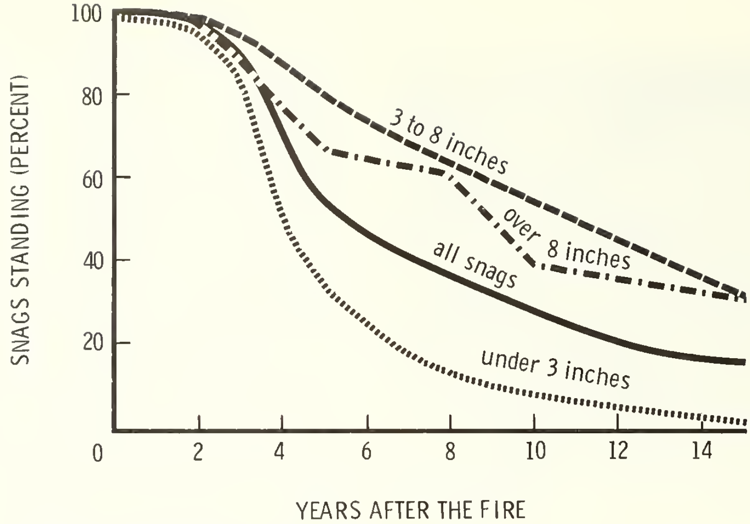



*Figure 26.—Percentage of lodgepole pine snags still standing, by year and diameter class, Sleeping Child Burn, Bitterroot National Forest, Montana, 1962-1976 (Lyon 1977).*

**Table 9.**—Average number of snags per acre by size class and year of count, Sleeping Child Burn, Bitterroot National Forest, Mont. (Lyon 1977) (totals may not agree because of rounding)

| Size class (inches) | Year | | | | | |
|---|---|---|---|---|---|---|
| | 1962 | 1963 | 1966 | 1969 | 1971 | 1976 |
| Under 3 | 266 | 265 | 96 | 41 | 28 | 4 |
| 3 to 8 | 159 | 156 | 124 | 103 | 85 | 50 |
| 8 to 12 | 64 | 62 | 40 | 36 | 24 | 19 |
| Over 12 | 7 | 7 | 7 | 6 | 4 | 3 |
| *Total* | *497* | *390* | *268* | *186* | *141* | *75* |

Snags less than 3 inches (7.6 cm) in diameter fell at a rate of 27.9 percent, and nearly all were down in 15 years. Snags larger than 3 inches fell at an annual rate of 8.4 percent, but those larger than 8 inches (20.3 cm) fell sporadically. Overall, an average of 497 snags per acre was reduced to an average of 75 snags per acre after 15 years (table 9).

Aside from fire-created snags, sources of deadfall are suppression mortality, snow breakage and windthrow of live trees, dwarf mistletoe-related mortality, and almost inevitably, mountain pine beetle attack and subsequent mortality. Mountain pine beetle attack is often the mechanism that causes the lodgepole stand to break up. Cumulative mortality during a mountain pine beetle epidemic (about 11 years) frequently amounts to 85 percent or more of the large, 8-inch (20-cm) diameter trees in a lodgepole pine stand (Cole and Amman 1980).

Brown (1975) has characterized fuel cycles and fire hazard in lodgepole pine stands, as shown in figure 27. Curve A of that figure corresponds to what Muraro (1971) describes as typical fire hazard in lodgepole pine where young stands, especially dense ones, are most hazardous. Least hazardous are moderately dense to open advanced immature and mature stands. Hazard increases as stands become overmature and ground fuels build up from downfall and establishment of shade-tolerant species. Curve C depicts conditions not uncommonly found. Ground fuel quantities and fire potential remain relatively low throughout the life of the stand until it undergoes decadence. Individual stands can vary anywhere between curves A and C during younger growth periods, and develop higher fire potential at later periods of growth (curve B).

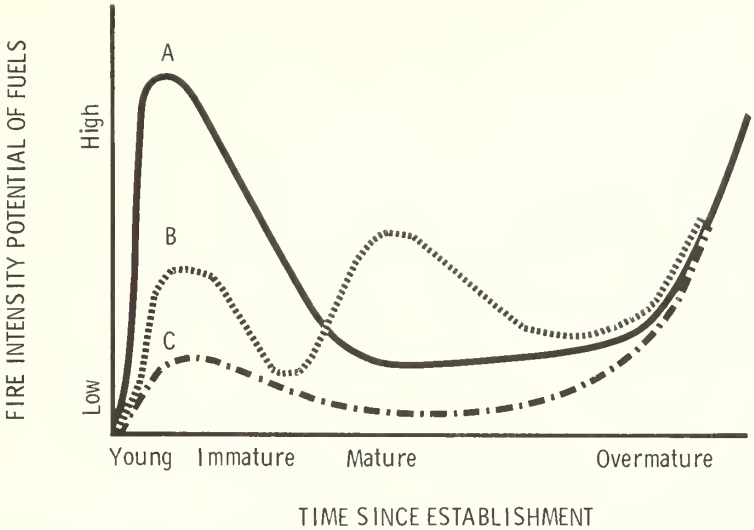



*Figure 27.—Fuel cycles and fire intensity potential in lodgepole pine (Brown 1975).*

## Role of Fire

In habitats below about 7,500 ft (2 286 m) the role of fire in seral lodgepole forests is almost exclusively as an agent that perpetuates or renews lodgepole pine. Without periodic disturbance, the shade-tolerant species replace lodgepole because it does not regenerate well on duff or under shaded conditions. Fire interrupts the course of successsion and increases the proportion of lodgepole with each burn. Within 50 to 100 years following a severe fire in a lodgepole-dominated stand, a reestablished lodgepole pine forest will exist even though shrubs and herbaceous cover may become dominant immediately following the burn.

Holocaust (large stand-replacing) fires play a definite role in the ecology of lodgepole pine stands. The natural periodicity of fire in seral lodgepole stands probably ranges from less than 100 years to about 500 years (Hendrickson 1970). The interval between any two fires in one area might be only a few years (Brown 1975). Recurring cool fires may thin the stand or otherwise rejuvenate it without doing serious damage. Stands greater than 60 to 80 years old, however, become increasingly flammable due to overcrowding (suppression mortality), mountain pine beetle outbreaks, dwarf mistletoe infestations, and fire-killed timber (snags) from previous fires. Eventually a chance ignition sets off a major conflagration. In certain areas such a fire can cover thousands of acres. Vast tracts of lodgepole can develop in this way as the serotinous cones open and shower the burn with seeds. The Sleeping Child burn on the Bitterroot National Forest in western Montana is an extreme example in modern times.

The almost exclusive dominance of lodgepole pine in the lodgepole pine community types is attributed in large part to fire. Pfister and others (1977) suggest the following reasons for the absence of other species on lodgepole pine climax series sites:

1. Historic, repeated wildfires over large areas may eliminate seed sources of potential shade-tolerant competitors.
2. Light ground fires may remove invading shade-tolerant competitors from the understory.
3. Dense stands may prevent regeneration of all conifers for up to 200 years in the absence of disturbance or stand deterioration.
4. Sites may be unfavorable for the establishment of other conifers. (In Montana, the best example of this situation is the PICO/PUTR h.t.)

The PICO habitat type (PICO/PUTR) near West Yellowstone is an example of a true lodgepole pine climax situation. Fire's role in succession on these sites is poorly understood. Apparently, fire is not required for regeneration. The local soil, composed of almost pure obsidian sand, and the occurrence of severe yearlong frosts create physiological problems that lodgepole alone can tolerate. The forest in this area is fairly open with numerous age classes of self-replacing lodgepole pine and a low grass and shrub understory (fig. 28). Fuels are discontinuous both on the ground and in the canopy. Evidence of past fires exists throughout these stands in the form of charcoal, both on the surface and in the soil.

*Figure 28.—A PICO/PUTR community type near West Yellowstone, Mont. (Gallatin National Forest). Special soil and climatic conditions allow lodgepole pine to dominate this site without serious competition from other species. Fire's role is poorly understood on such sites. (Bruce Clayton photo.)*

Above 7,500 ft (2 286 m) the role of fire in lodgepole forests appears to differ from the classic pattern. At these altitudes the fire season is relatively short, productivity is low, mountain pine beetle activity is inhibited by low temperatures and the short growing season, and the overall pattern of fire dependence is correspondingly subdued. Fire frequency more closely resembles that of subalpine forests (about 150 years in the Northern Rockies). Romme (1980) has estimated a mean fire interval of 300 to 400 years for stand-destroying fires in subalpine forests of Yellowstone National Park. Ordinarily, the spread of fire is extremely limited. Small, lightning-caused fires burn out patches of forest several acres in area and then die out. The result is a mosaic of age classes, not the uniform single-aged forests prevalent on many lower elevation sites (Day 1972).

## THE LODGEPOLE PINE FIRE CYCLE

Brown (1975) summarizes the lodgepole pine fire cycle and the many interrelated factors that influence it in figure 29. His discussion of fire cycles and community dynamics in lodgepole pine forests is an important source of information on the role of fire in lodgepole pine forests. Brown also discusses the differential effects of fires of varying severity on lodgepole pine forests. He emphasizes the critical role of fuel and duff moisture in determining fire severity and, consequently, fire effects.

## FIRE AND THE MOUNTAIN PINE BEETLE

The roles of fire and mountain pine beetle are inextricable in most lodgepole pine forests. The following excerpt from Amman (1977) describes this interrelationship:

> *ROLE OF THE MOUNTAIN PINE BEETLE IN LODGEPOLE PINE ECOSYSTEMS*
>
> The role of the beetle differs in conjunction with the two basic ecological roles of lodgepole pine, where lodgepole pine is seral and where it is persistent or climax. The beetles' continued role in the seral stands will depend upon the presence of fire.
>
> *Role of Mountain Pine Beetle Where Lodgepole Pine Is Seral*
>
> **Absence of fire**: Lodgepole pine stands depleted by the beetle and not subjected to fire are eventually succeeded by the more shade-tolerant species consisting primarily of Douglas-fir at the lower elevations and subalpine fir and Engelmann spruce at the higher elevations throughout most of the Rocky Mountains. Starting with a stand generated by fire, lodgepole pine grows at a rapid rate and occupies the dominant position in the stand. Fir and spruce seedlings also established in the stand grow more slowly than lodgepole pine.

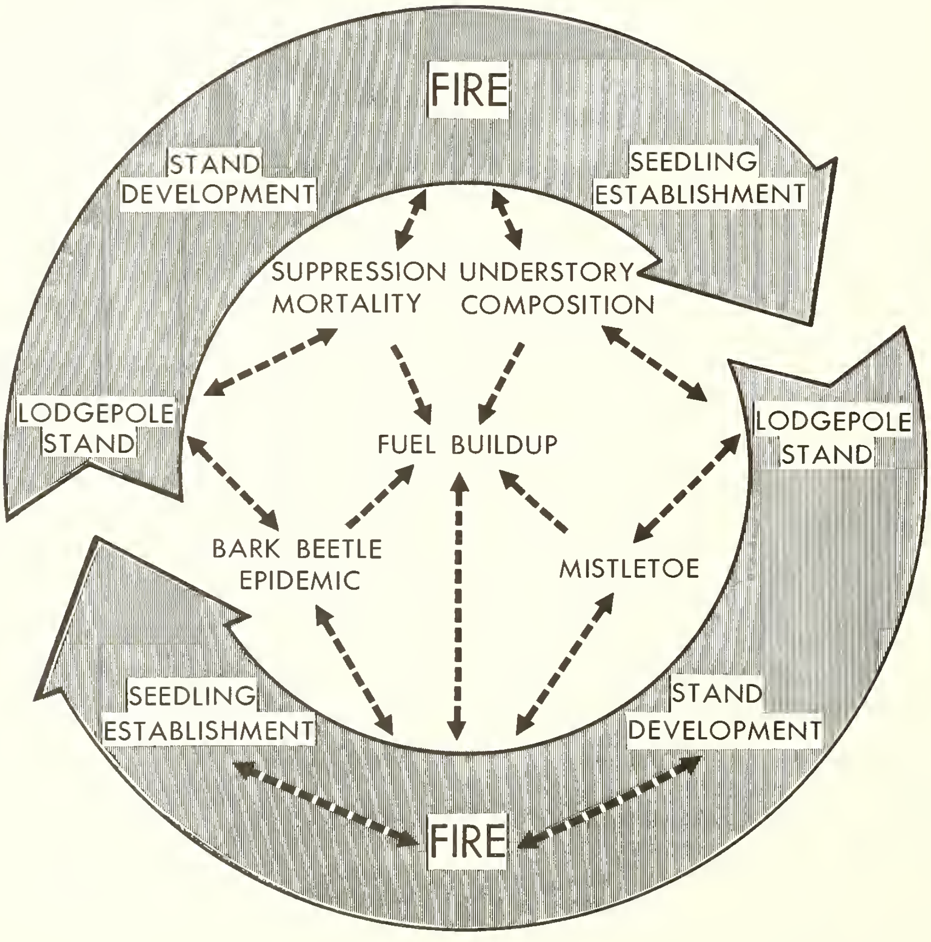



*Figure 29.—Lodgepole pine fire cycle showing interrelationships among influences (Brown 1975).*

With each infestation, the beetle kills most of the large, dominant lodgepole pines. After the infestation, both residual lodgepole pine and the shade-tolerant species increase their growth. When the lodgepole pines are of adequate size and phloem thickness, another beetle infestation occurs. This cycle is repeated at 20- to 40-year intervals depending upon growth of the trees, until lodgepole pine is eliminated from the stand.

The role played by the mountain pine beetle in stands where lodgepole pine is seral is to periodically remove the large, dominant pines. This provides growing space for subalpine fir and Douglas-fir, thus hastening succession by these species. The continued presence of the beetle in these mixed-species stands is as dependent upon fire as that of lodgepole pine. Without it both are eliminated.

**Presence of fire**: Where lodgepole pine is seral, forests are perpetuated through the effects of periodic fires (Tackle 1964a). Fires tend to eliminate competitive tree species such as Douglas-fir, the true firs, and spruces. Following fire, lodgepole pine usually seeds in abundantly. Serotinous cones attached to the limbs of the tree open because of the intense heat of the fire and release their seed (Clements 1910; Lotan 1975).

Large accumulations of dead material caused by periodic beetle infestations result in very hot fires when they do occur (Brown 1975). Hot fires of this nature eliminate Douglas-fir, which otherwise is more resistant to fire damage than lodgepole pine. The dominant shade-tolerant species are eliminated, resulting in a return to a pure lodgepole pine forest. On the other hand, light surface fires would not be adequate to kill large, thickbarked Douglas-fir and return lodgepole pine to a dominant position in the stand.

Following regeneration of lodgepole pine after fire, the mountain pine beetle-lodgepole interactions would be similar to those described in the absence of fire. A fire may interrupt the sere at any time, reverting the stand back to pure lodgepole pine. However, once succession is complete, lodgepole pine seed will no longer be available to seed the burned areas except along edges where the spruce-fir climax joins persistent or climax lodgepole pine.

***Role of Mountain Pine Beetle Where Lodgepole Pine Is Persistent or Climax***

Lodgepole pine is persistent over large acreages, and because of the number of shade-tolerant individuals of other species found in such persistent stands, the successional status is unclear (Pfister and Daubenmire 1975). In any case, lodgepole pine persists long enough for a number of beetle infestations to occur. In such cases and those of a more limited nature when lodgepole pine is climax because of special climatic or soil conditions, the forest consists of trees of different sizes and ages ranging from seedlings to a few overmature individuals. In these forests, the beetle infests and kills most of the lodgepole pines as they reach larger sizes. Openings created in the stand as a result of the larger trees being killed, are seeded by lodgepole pine. The cycle is then repeated as other lodgepole pines reach sizes and phloem thicknesses conducive to increases in beetle populations.

The result is two- or three-story stands consisting of trees of different ages and sizes. A mosaic of small clumps of different ages and sizes may occur. The overall effect is likely to be more chronic infestations by the beetle because of the more constant source of food. Beetle infestations in such forests may result in death of fewer trees per hectare during each infestation than would occur in even-aged stands developed after fires and in those where lodgepole pine is seral.

Fires in persistent and climax lodgepole pine forests should not be as hot as those where large epidemics of beetles have occurred. Smaller, more continuous deposits of fuel are available on the forest floor. The lighter beetle infestations, and thus lighter accumulations of fuel, would result in fires that would eliminate some of the trees but probably would not cause total regeneration of the stand. This would be beneficial to the beetle because a more continuous supply of food would be maintained. Where large accumulations of fuel occur after large beetle epidemics, fire would completely eliminate the beetles' food supply from vast acreages for many years while the entire stand of trees grow from seedlings to sizes conducive to beetle infestation.

The mountain pine beetle's evolutionary strategies have been successful. It has exploited a niche that no other bark beetle has been able to exploit, that of harvesting lodgepole pine trees as they reach or slightly before they reach maturity. Such trees are at their peak as food for the beetle. Harvesting at this time in the age of the stand maintains the vigor of the stand, and keeps the stand at maximum productivity. (End of Amman 1977 excerpts.)

## Generalized Forest Succession

The theoretical climax forest on Fire Group Seven sites will vary according to habitat type as shown in figure 30 (subsequent numbers in this section refer to fig. 30). Except for the lodgepole pine community types and the PICO/PUTR habitat type, however, the climax situation is rarely achieved. Fire almost always interrupts succession before a near climax condition develops.

Following a stand-destroying fire on a Group Seven site, a short-lived herb/shrub stage dominates. This stage is short-lived in the sense that lodgepole pine seedlings quickly become established and overtop the undergrowth. A fire in the herb/shrub stage (No. 1) will, however, extend its period of dominance. Recurring fire at frequent intervals could conceivably maintain the site in herbs and shrubs. A fire during the seedling/sapling stage will also return the site to herbs and shrubs (No. 2). The likelihood of a fire at this stage is not great on most Group Seven sites.

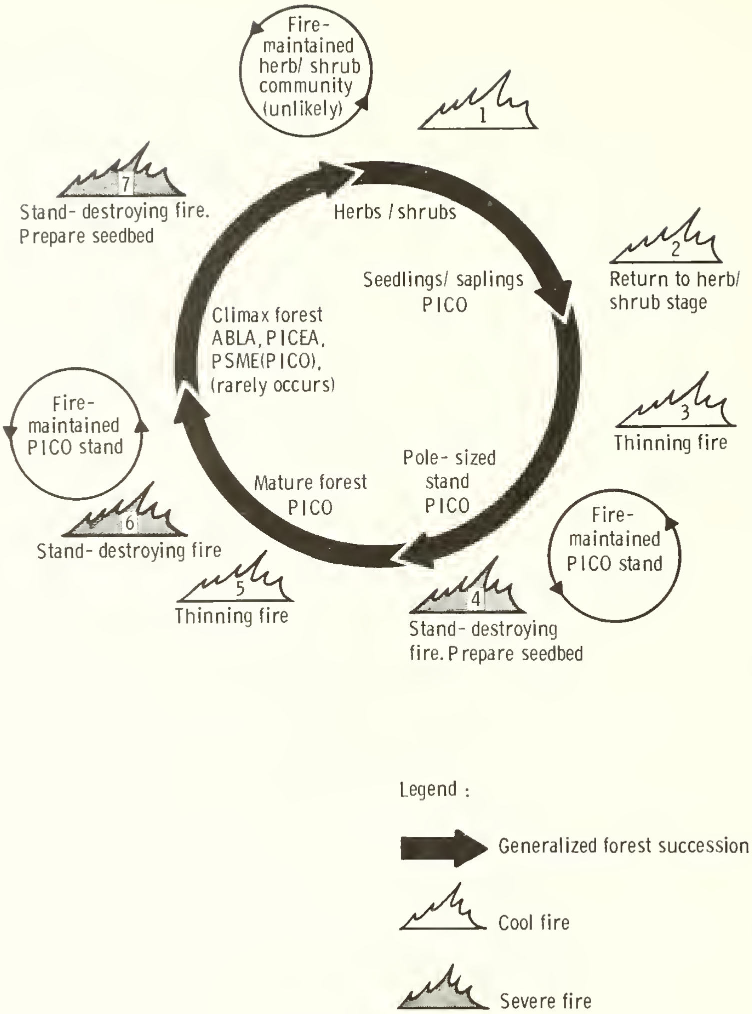



*Figure 30.—Generalized forest succession in Fire Group Seven: cool habitat types usually dominated by lodgepole pine.*

The effect of a fire during the pole stage will depend on fire severity. A cool fire (No. 3) will thin the stand while a severe fire (No. 4) will destroy the stand. Since pole-sized lodgepole pine usually contain serotinous cone crops, perodic fire at this stage can result in a fire-maintained lodgepole pine stand. The effect of fire in a mature lodgepole forest is essentially the same as in the pole forest. A cool fire thins the stand and a severe fire recycles the stand (No. 5 and 6). The probability of a severe stand-destroying fire greatly increases as a previously unburned mature stand starts to break up and an understory of climax species develops. It is usually at this stage rather than the climax stage that fire destroys the stand (No. 7).

## Successional Pathways

Hypothetical successional pathways for Fire Group Seven forests are illustrated in figure 31 (subsequent states and numbers in this section refer to fig. 31).

Starting with a herb/shrub state (state A) two major paths exist depending on whether the site is classified as a lodgepole pine community type or habitat type, or whether the site is a potential Douglas-fir, spruce, or subalpine fir climax.

### LODGEPOLE PINE CLIMAX TYPES

Lodgepole pine is essentially the only tree species present on PICO climax types. Consequently, succession is dominated by lodgepole pine regardless of fire occurrence. Stand characteristics may, however, reflect fire history. The herbaceous state (state A) is followed by a seedling/sapling state (state B1). Any fire in this state will return the site to a herbaceous condition (No. 1). In the absence of fire, a fully or overstocked lodgepole pine stand will develop (state C1). A moderate to severe fire can destroy such a stand (No. 2). Stand development, in the continued absence of fire, will progress to the mature forest condition (state D1). Depending on inital stand density and regeneration period, a lodgepole pine understory may or may not exist.

The next step in fire-free succession is the breaking up of the overstory due to insect attack, decadence, windthrow, and so forth (state E1). As openings are created, either understory trees assume overstory status or regeneration is initiated in the openings. A severe fire can occur during the mature forest state and result in total stand destruction (No. 3). Such a stand-destroying fire is more likely to occur after the stand begins to break up (No. 4) because of increased fuel loads and lower surface fuel moistures. If fire does not occur, a climax forest may

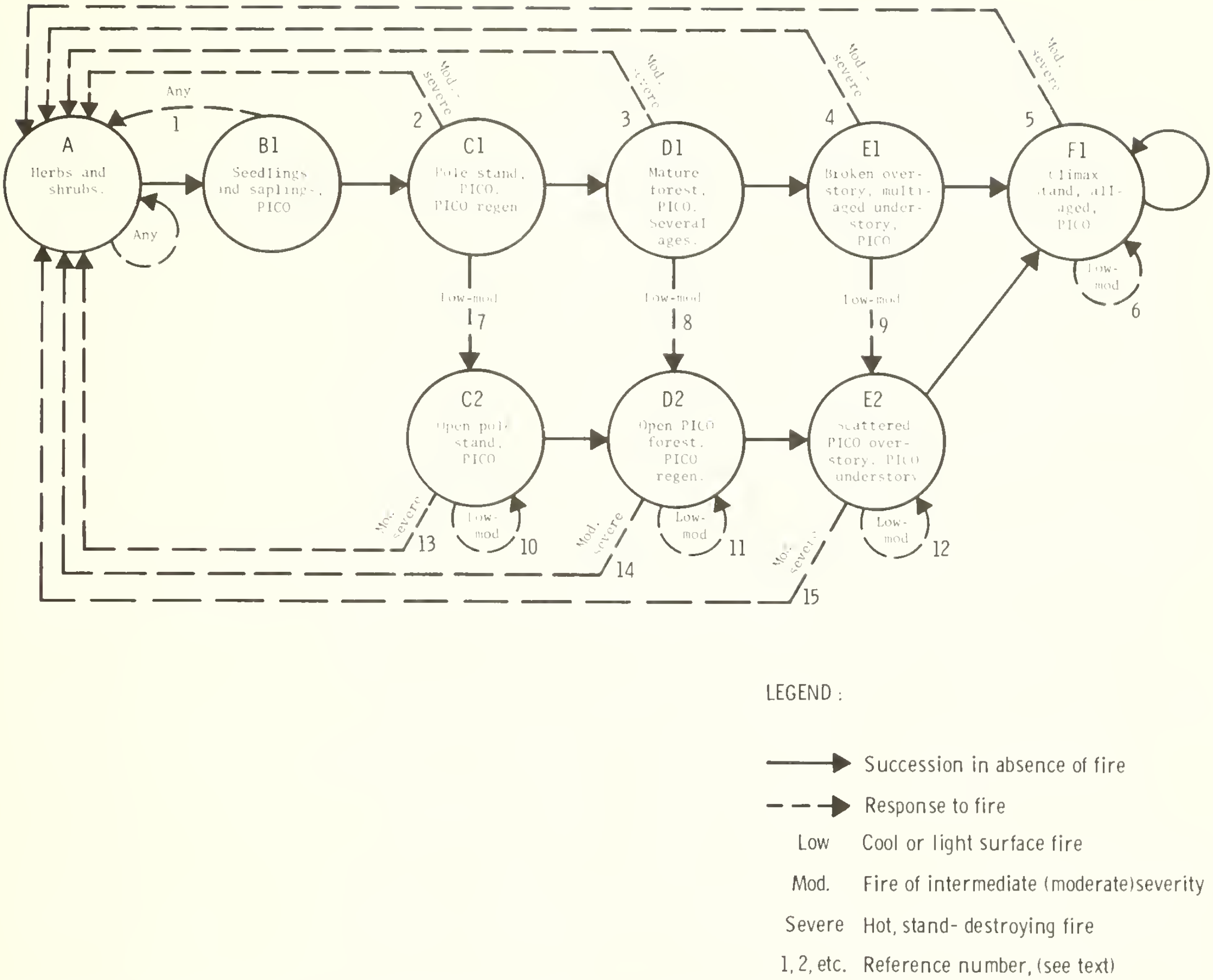



*Figure 31.—Hypothetical fire-related successional pathways for Fire Group Seven habitat types.*

develop on the site (state F1). A severe fire at this state would return the site to the herbaceous condition (No. 5). A cool to moderately severe fire would maintain the climax condition (No. 6).

A low to moderate intensity fire in a pole stand (state C1) would thin out the overstory and remove regeneration (No. 7). The resulting open pole stand (state C2) would develop into a open forest condition (state D2) in the absence of fire. This same condition would result from a cool or moderately severe fire in the mature forest state (No. 8). Eventually, if fire does not occur, a new lodgepole pine stand will develop beneath a scattered lodgepole overstory (state E2). This situation will also result from a cool to moderate fire in a stand undergoing breakup (No. 9). Subsequent low to moderate severity fires in any of the fire-created open stand conditions (states C2, D2, and E2) would primarily affect understory regeneration (No. 10, 11, and 12). Severe fires would likely result in stand replacement (No. 13, 14, and 15).

## DOUGLAS-FIR, SPRUCE, AND SUBALPINE FIR CLIMAX TYPES

Forest succession in the presence and absence of fire on Group Seven Douglas-fir, spruce, and subalpine fir sites is only slightly different from that described for lodgepole sites. Lodgepole pine dominates most stages of succession regardless of indicated climax. As indicated in figure 31, stand development is essentially the same as for lodgepole climax sites. The major difference is in understory composition. The seedling/sapling state (state B2) is dominated by lodgepole pine, but some climax species seedlings will also be present. The pole state (state C3) is also dominated by lodgepole, but the understory is likely to be dominated by more shade-tolerant climax species. In the continued absence of fire, this trend will continue through the mature forest state (state D3) and the breakup state (state E3). Given a long enough time without fire, climax species will capture the overstory and maintain control of the site (state F2), even if low to moderate severity fires do occur (No. 16). Severe fires at any stage of development after seedling establishment, except the climax state, will return the site to the herbaceous state (No. 17, 18, 19, and 20).

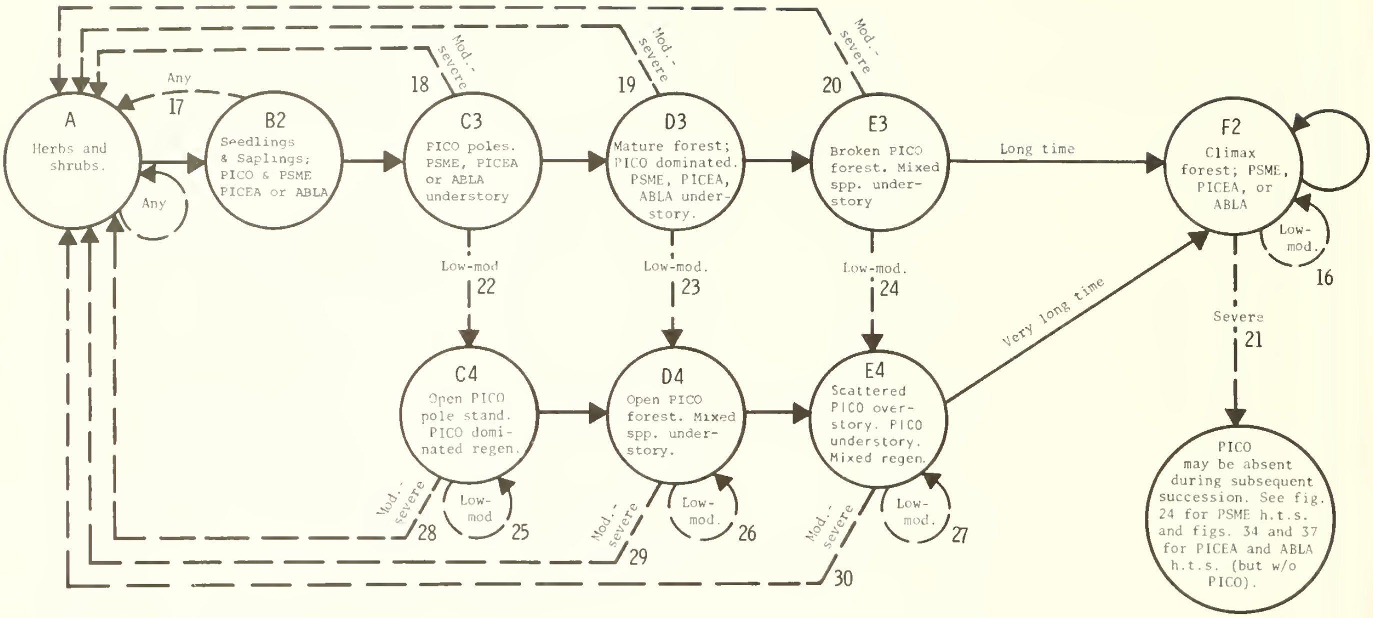



*Figure 31.—(con.)*

Lodgepole pine will be essentially absent during succession following a severe fire (No. 21) in the climax state (state F2). Lodgepole pine would be absent from a true climax stand; hence, no seed source would be available to place lodgepole pine in the postfire stand. Succession following a severe fire in state F2 would be similar to that described in figure 24 (Fire Group Six) for Douglas-fir habitat types or in figures 34 and 37 (Fire Group Eight and Nine) (see pages 59, 60, and 65) for subalpine fir and spruce habitat types, except that lodgepole pine would be absent.

Low to moderate severity fires in the pole, mature, or broken stand states (No. 22, 23, and 24) will result in open lodgepole stands with lodgepole dominated regeneration. Subsequent low to moderate fires (No. 25, 26, and 27) would insure lodgepole pine continued dominance. The absence of fire allows climax species to develop in the understory. This could lead, theoretically, to the eventual establishment of the climax forest (state F2) given a long enough fire-free period. Severe fires in the open stand conditions would return the site to herbs and shrubs (No. 28, 29, and 30).

## Fire Management Considerations

Perhaps the primary fire management consideration in the group's habitat types is protection from unwanted fire during extended periods of drought and during severe fire weather conditions. Fires at such times often crown and become holocausts that result in complete stand mortality if the lodgepole stand is ready physiognomically to burn (Despain and Sellers 1977).

### FIRE USE

Opportunities for fire use are limited in natural stands because of the low fire resistance of lodgepole pine, spruce, and subalpine fir. The other side of this problem is that during "safe" fire weather, it is often difficult to sustain a fire in Group Seven stands. Low to medium intensity surface fires, however, do occur in Group Seven stands. Thus, there may be opportunities to use prescribed fires to accomplish specific management objectives.

Prescribed fire has been suggested as a management tool for controlling dwarf mistletoe (*Arceuthobium* spp.). According to Alexander and Hawksworth (1975), prescribed burning, in relation to mistletoe control, can serve two purposes: (1) eliminate infected residual trees in logged-over areas, and (2) destroy heavily infected stands on unproductive sites so that they can be replaced by young healthy stands.

### SLASH DISPOSAL AND SITE PREPARATION

The primary use of prescribed fire in this group has been and undoubtedly will continue to be for hazard reduction and site preparation in conjunction with tree harvesting. Broadcast burning and windrowing and burning have been the most often used methods of accomplishing these tasks. Successful broadcast slash burning in Group Seven stands will usually yield increased forage production for big game. Slash disposal of any kind will aid big game movement through these stands.

Managers should use the information contained in the two-volume proceedings of the "Management of Lodgepole Pine Ecosystems" symposium (Baumgartner 1975) as a guide for fire management actions in Group Seven habitat types. The following excerpt by Lotan (1975) from that proceedings summarizes current knowledge regarding slash disposal and seedbed preparation.

> Slash disposal methods are important in lodgepole pine management because harvesting overmature stands leaves large quantities of logging debris as a fire hazard, and for many areas, natural regeneration is obtained principally from serotinous cones in the slash. Methods

used to lower the fire hazard include broadcast burning, piling in "jack piles" or windrows and burning, breaking and flattening with rolling choppers, and lopping and scattering. More recently, there has been considerable interest in chipping and selling this material.

Broadcast burning results in varying densities of reproduction depending upon the distribution and intensity of the fire. Variations in fuel, humidity, slope, and other factors have made it difficult to obtain uniformly distributed reproduction of desired density. Piling and burning is a more direct method of slash disposal, but heat is concentrated and seed stored in the piled slash is likely to be destroyed. If slash is concentrated and not burned, seedlings may fail to come up through it, and the fire hazard will remain high for many years. Some windrowing was done in the pulpwood logging described by Curtis and Tackle (1954) on the Targhee National Forest. If natural regeneration is desired, special effort may be needed to scatter the slash to properly distribute the seed.

Lopping and scattering will provide more than adequate stocking, but may or may not reduce the fire hazard (Boe 1952). It is most advantageous when close utilization is practiced and where natural regeneration is marginal; i.e., where there is need to use as much of the stored seed as possible.

Tackle's (1954b) conclusions on slash disposal were: (1) burning is not essential to obtain adequate stocking, (2) time must be allowed between felling and piling to allow cones to open, (3) piling slash with toothed dozer blades will shake seed from the slash and prevent excessive soil disturbance, (4) burned areas should be kept to a minimum, and (5) cone opening is dependent upon factors such as cone height above ground and orientation toward solar heat.

Timing of slash disposal is important. To melt the resin bond holding the cone scales, slash must be exposed to radiant energy near the ground and must be dozer-piled before the seed germinates (Tackle 1954b, Lotan 1964a). On slash, closed cones that are well above ground behave like those on a tree—they remain closed, and stored seed stays viable for years. Closed cones on or near the ground vary in behavior: those that receive enough solar heat open and release seed (Lotan 1964a); others remain closed and their seed loses germinative capacity (Tackle 1954b, Ackerman 1966).

In the Northern Rocky Mountains, when seed is released in adequate amounts upon a favorable seedbed free of competing vegetation, seed germinates rapidly as soon as conditions become favorable. Seed dispersed during the fall and winter will often have optimum germinating conditions following snowmelt when both moisture and temperature are favorable. In our studies on the Targhee and Gallatin National Forests, 90 percent of germinating seedlings emerged the first 2 weeks in July, following snowmelt in late June (Lotan 1964b). From a management viewpoint, it is difficult to say what constitutes a favorable seedbed. In some localities, overstocking is a problem; in others, understocking is a problem.

Usually, treatments that remove competing vegetation and increase the odds of seed falling upon a favorable microsite will greatly increase numbers of seedlings that survive. We may or may not get enough trees on seedbeds that are undisturbed or burned, depending upon the amount of viable seed per acre and how much the seedbed is unfavorable. There are many types of burns and many different types of competing vegetation. In several studies where attempts have been made to remove cones or cone-bearing slash, stocking was frequently lower, but seldom significantly lower, than on areas where slash was handled normally. Apparently, seed was still dispersed during slash disposal. Frequently, burned areas were slower in returning to a stocked condition, but stocking eventually came close to management objectives (Tackle 1964b).

## STOCKING CONTROL

Lotan's (1975) discussion of stocking control is also relevant to fire management in Group Seven lodgepole pine stands. Excerpts from this discussion follow:

> There are a number of possible opportunities to regulate stocking through manipulation of the seed supply or of the microenvironment. It is frequently possible to secure adequate stocking on areas where seed-seedling ratios and stored seed estimates indicate low levels of stocking. This might be accomplished by any one of the following: intensifying site preparation, treating slash to assure maximum seed release, treating an area to reduce seed loss to rodents, or by using a combination of these treatments. Conversely, stocking may be reduced by limiting site preparation, reducing disturbances of the soil surface during logging, or by treating slash to destroy a portion of the stored seed.
>
> Whether we want to reduce overstocking or increase understocking, there is much we can do to affect regeneration. Manipulating seedbed conditions usually brings dramatic results, particularly when some form of scarification is used.
>
> The seed available for natural regeneration varies considerably and is a major factor. It will account for much of the variability that we get, as shown in study of green vs. dry slash (Lotan 1964b):
>
> | | **Gallatin N.F.** | **Lewis and Clark N.F.** |
> |---|---|---|
> | | *Seedlings per acre* | |
> | Green slash | 7,067 | 22,175 |
> | Dry slash | 1,967 | 10,475 |
>
> There were 3 to 5 times as many seedlings on the Lewis and Clark National Forest as on the Gallatin National Forest.

Next we can use seed-seedling ratios for different habitat types and seedbed conditions to account for our losses. For example, after 5 years, the best seedbed tested on the following sites varied considerably in seed-seedling ratios:

| Site | Habitat type | Lowest seed-seedling ratio |
|---|---|---|
| Moose Creek Plateau | *Abies/Vaccinium* | 30:1 |
| Island Park Flat | *Pseudotsuga/ Calamagrostis* | 50:1 |
| West Yellowstone Flat | *Pinus/Purshia* | 300:1 |

Knowledge of seed-seedling ratios for a particular site and seedbed condition can be used with information on seed supply to estimate feasibility of a particular regeneration method.

We need to distinguish between overstocking and understocking problems in lodgepole pine regeneration. Comparing again regeneration on the Gallatin National Forest and Lewis and Clark National Forest, we can readily see the implications in precommercially thinning. One stand is measured in thousands of stems and the other in tens of thousands. In areas like the Lewis and Clark and Bitterroot, overstocking is the problem. There is much we could do that would reduce stocking so fewer stems per acre need to be removed.

On the other hand, artificial regeneration has been required on the Gallatin National Forest and on many forests in Region 4, in some cases because of failure to recognize the dearth of seed stored in closed cones and the importance of cone serotiny, in others because of soil problems. (End of Lotan 1975 excerpts.)

The primary concern in the fire management of many lodgepole pine forests is the prevention of stand-destroying fires over large areas. Timber harvest for a variety of products and subsequent slash disposal are the primary means to this end. Harvest schedules should be developed and implemented to create age-class mosaics of lodgepole pine. This will minimize the areal extent of stand-destroying fires. Silvicultural practices designed to harvest trees susceptible to mountain pine beetle before the trees are attacked (Cole and Amman 1980) can greatly reduce the threat of severe fires in second-growth stands of lodgepole pine. The use of lodgepole pine for firewood, poles, posts, wood chips, and sawlogs provides ample opportunities for fuel management-related harvesting.

In some wilderness areas, periodic crown fires play a vital role in natural development of lodgepole pine ecosystems, and their use should be considered when consistent with the need to protect human life, property, and resource values outside wilderness.

## FIRE GROUP EIGHT: DRY, LOWER SUBALPINE HABITAT TYPES

| ADP code | Habitat type-phase (Pfister and others 1977, Roberts 1980) | Montana forest region (Arno 1979) |
|---|---|---|
| | *Picea/Linnaea borealis* h.t. (PICEA/LIBO), spruce/twinflower. | Central (Bearpaw Mountains only). |
| 430 | *Picea/Physocarpus malvaceus* h.t. (PICEA/PHMA), spruce/ninebark. | South-central. |
| 480 | *Picea/Smilacina stellata* h.t. (PICEA/SMST), spruce/starry Solomon's seal. | Central, southwestern, and south-central. |
| 691 | *Abies lasiocarpa/Xerophyllum tenax* h.t.-*Vaccinium globulare* phase (ALBLA/XETE-VAGL), subalpine fir/beargrass-blue huckleberry phase. | North-central and southwestern. |
| 733 | *Abies lasiocarpa/Vaccinium scoparium* h.t.-*Thalictrum occidentale* phase (ABLA/VASC-THOC), subalpine fir/grouse whortleberry-western meadowrue phase. | Central, southwestern, and south-central. |
| 750 | *Abies lasiocarpa/Calamagrostis rubescens* h.t. (ABLA/CARU), subalpine fir/pinegrass. | North-central, central, southwestern, and south-central. |
| 770 | *Abies lasiocarpa/Clematis pseudoalpina* h.t. (ALBA/CLPS), subalpine fir/virgin's bower. | North-central, central, southwestern, and south-central. |
| 780 | *Abies lasiocarpa/Arnica cordifolia* h.t. (ABLA/ARCO), subalpine fir/heartleaf arnica. | North-central, central, and southwestern. |
| 792 | *Abies lasiocarpa/Carex geyeri* h.t.-*Pseudotsuga menziesii* phase (ABLA/CAGE-PSME), subalpine fir/elk sedge-Douglas-fir phase. | Central, southwestern, and south-central. |

Fire Group Eight consists of dry, lower subalpine habitat types where spruce or subalpine fir are the indicated climax species but do not typically dominate seral stands. Douglas-fir alone, or more commonly a mixture of Douglas-fir, lodgepole pine, and often spruce, dominates most seral stands; subalpine fir, and on some sites spruce, are minor stand components. Exceptions to this general rule include ABLA/VASC-THOC sites where Douglas-fir is essentially absent and ABLA/CAGE-PSME sites where lodgepole pine and spruce are essentially absent. Limber pine is a long-lived seral dominant on ABLA/CLPS sites. Whitebark pine occurs as an accidential or minor seral species throughout the Fire Group and may be a major seral component in some ABLA/CLPS stands.

The dominance of Douglas-fir and lodgepole pine in this group may be in part due to periodic wildfire that sets back the invasion of spruce and subalpine fir.

Fire Group Eight stands usually produce luxuriant undergrowth. Common grasslike species are beargrass, pinegrass, and elk sedge. Shrub layers are dominated by one or more of the following species: Oregon grape, common juniper, mountain lover, ninebark, russet buffaloberry, twinflower, white spiraea, snowberry, blue huckleberry, and grouse whortleberry.

Among the more prevalent forbs are: heartleaf arnica, broadleaf arnica, sweet cicely, western meadowrue, pyrola, false Solomon's seal, and violet. Other forbs include: red baneberry, showy aster, timber milkvetch, wild strawberry, elkweed, sweetscented bedstraw, geranium, virgin's bower, northern bedstraw, fairy bells, valerian, starry Solomon's seal, mountain death camas, and cleft leaf groundsel.

## Forest Fuels

Downed dead woody fuel loading in Fire Group Eight stands averages about 20 tons/ acre (about 4.5 kg/m$^2$). Maximum loads may greatly exceed this value.

Most of the dead woody fuel is greater than 3 inches (7.6 cm) in diameter. A large amount of material in the 10- and 20-inch (25- and 50-cm) diameter class is common in these stands (fig. 32 and table 10).

As is the case in many subalpine fir habitat types, live fuels can contribute significantly to overall fire hazard during dry conditions. Dense understories develop in many Group Eight stands and provide fuel ladders to the overstory tree crowns, although some stands are devoid of such understories (fig. 32).

Relatively deep duff layers may form in Group Eight stands (table 10). When dry, fire in the duff can cause considerable mortality by heating the shallow roots of subalpine fir and Engelmann spruce.

## Role of Fire

Fire history data for Fire Group Eight habitat types east of the Continental Divide are lacking. Arno (1980) has, however, summarized available fire history data for lower subalpine forests from other parts of the Northern Rocky Mountains. For example, he reports that almost 60 percent of mature western Montana ABLA/XETE stands (greater than 100 years old) show obvious evidence of ground fire after stand establishment.

The occurrence of periodic low to moderate severity fires favors Douglas-fir and lodgepole pine. Such fires set back invasion by the more tolerant spruce and subalpine fir, which in the absence of fire form dense understories and eventually take over the site. Fires of moderate severity probably help Douglas-fir maintain a position of dominance or codominance with lodgepole in many Group Eight stands. The more fire-resistant Douglas-fir has a better chance of surviving such fires and is able to successfully regenerate in fire-created openings where

A

B

*Figure 32.—Examples of Fire Group Eight stand and fuel conditions near Lincoln, Mont., Helena National Forest. Both stands are Engelmann spruce-subalpine fir stands on a subalpine fir/beargrass h.t.-blue huckleberry phase. Stand age, total fuel load by size class, and duff depths are given in table 10.*

**Table 10.**—Fuel loading by size class and duff depth for Fire Group Eight stands shown in figure 15 (source: Fischer 1981b)

| Stand number | Habitat type | Age | Duff depth | Size class (inches) 0-1/4 | 1/4-1 | 1-3 | 3-6 | 6-10 | 10-20 | 20 + | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Years* | *Inches* | *Tons per acre* | | | | | | | |
| 20A | ABLA/XETE-VAGL | 165 | 3.4 | 0.5 | 1.4 | 3.8 | 16.7 | 22.0 | 6.6 | 0 | 51.0 |
| 23A | ABLA/XETE-VAGL | 150 | 3.1 | 0.6 | 1.9 | 3.2 | 11.7 | 16.3 | 0 | 0 | 33.7 |

mineral soil has been exposed. Severe, stand-destroying fire will generally favor lodgepole pine on many of these sites. Some large, thick-barked Douglas-fir trees will often survive fires severe enough to kill all the lodgepole pine trees, thereby assuring the presence of Douglas-fir in the new stand.

Fire frequencies for this group probably fall between those reported for Fire Group Seven lodgepole pine stands (about 50 years) and those identified for the more moist lower subalpine types of Fire Group Nine (90 to 130 years).

## Generalized Forest Succession

The theoretical climax forest on Fire Group Eight habitat types is either subalpine fir or spruce. Either climax situation requires a very long fire-free period to develop and is, consequently, rarely found. More common is a near-climax situation characterized by a dense forest of subalpine fir and spruce, with abundant Douglas-fir, lodgepole pine, and often spruce in the overstory.

A stand-destroying fire in the climax (or near-climax) stage results in a shrub/herb stage (as shown in fig. 33, No. 1) followed by a seedling and sapling stage (subsequent numbers in this section refer to fig. 33). On most Group Eight sites Douglas-fir, lodgepole pine, and, on some sites, spruce seedlings will dominate, but subalpine fir seedlings are likely on ABLA/VASC-THOC sites and lodgepole and spruce seedlings are usually absent on ABLA/CAGE-PSME sites. Limber pine may be abundant on ABLA/CLPS sites along with whitebark pine. Whitebark pine may also occur on some ABLA/XETE-VAGL and ABLA/ARCO sites.

Any fire in the seedling/sapling stage will revert the site to shrubs and herbs (No. 2). Pole-sized stands are usually mixed stands of Douglas-fir and lodgepole except as previously indicated. A low to moderate severity fire in such a stand will favor the more fire-resistant Douglas-fir over the more fire-susceptible lodgepole pine (No. 3). A severe fire, however, will destroy the stand, thereby favoring the early serotinous cone-producing lodgepole pine over Douglas-fir (No. 4). Periodic fire could result in a fire-maintained lodgepole pine stand on some sites.

In the continued absence of fire, a mature stand will develop. Lodgepole pine and Douglas-fir will dominate the overstory, but a dense understory of spruce and subalpine fir is likely on many sites. A cool fire will remove much of this fire-susceptible understory and some of the lodgepole overstory thereby favoring the Douglas-fir (No. 5). A severe fire can destroy the stand and revert the site to shrubs and herbs (No. 6). Again, the serotinous-coned lodgepole will have an advantage in regenerating itself in the new stand. Periodic fire could maintain a lodgepole stand on some sites. If fire is absent for very long, a near-climax or climax forest will develop.

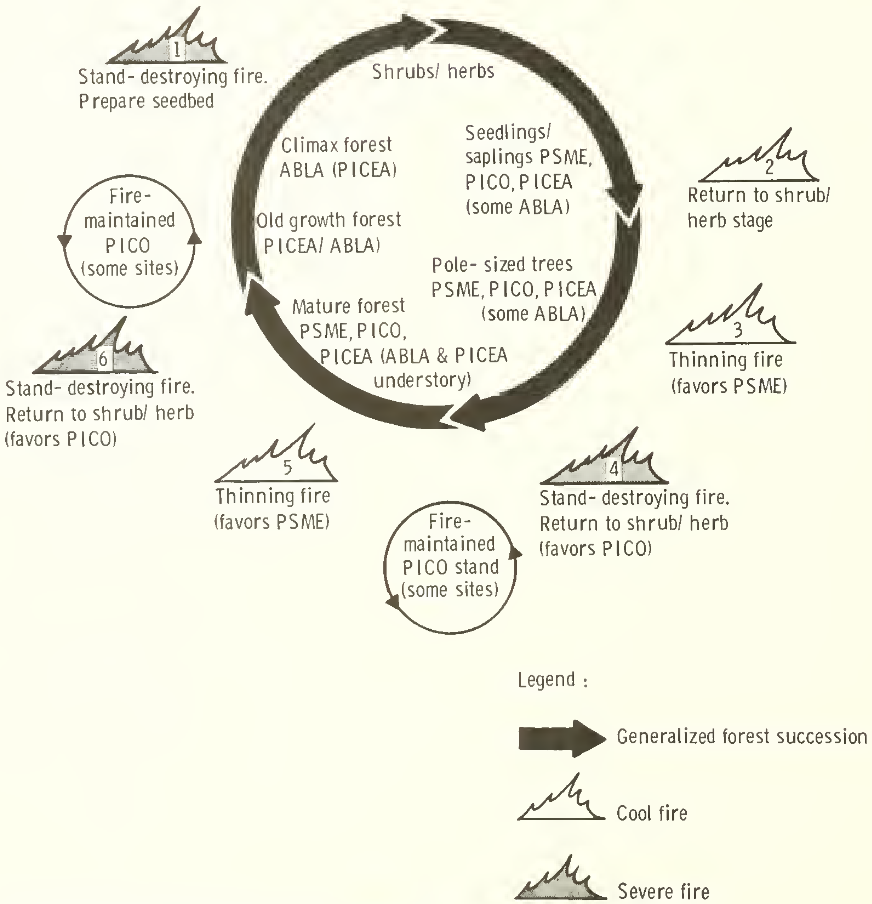



*Figure 33.—Generalized forest succession in Fire Group Eight: dry, lower subalpine habitat types.*

## Successional Pathways

The Group Eight hypothetical successional pathway diagram is shown in figure 34 (subsequent states and numbers in this section refer to fig. 34). The diagram is complicated by the general absence of Douglas-fir on ABLA/VASC-THOC habitats and of lodgepole pine and spruce on ABLA/CAGE-PSME habitats. Three major successional pathways are, consequently, identified for this fire group.

### MIXED SPECIES FOREST SUCCESSION

The mixed species pathway applies to all Group Eight habitat types except ABLA/VASC-THOC and ABLA/CAGE-PSME. Forest succession in the absence of fire proceeds from a transitional shrub/herb state (state A) to a seedling and sapling state in which Douglas-fir, lodgepole pine, spruce, and often subalpine fir are present (state B1). Any fire in state B1 will return the site to shrubs and herbs (No. 1). In the continued absence of fire, a mixed-species pole stand will develop (state C1) and eventually a mature mixed forest (state D1). Douglas-fir and lodgepole often dominate the pole and mature states, but spruce is often a vigorous competitor on some sites. In the unlikely event that fire-free succession continues, a near-climax state would occur (state F1) where spruce and subalpine fir dominate the overstory with scattered long-lived Douglas-fir trees. The understory of such a stand would be dominated by spruce and fir. Eventually, in the continued absence of fire, the theoretical climax state (state G1) dominated by either spruce or subalpine fir would occur.

Severe fires in the pole, mature, near-climax, and climax states would probably destroy the stand and temporarily return the site to the shrub/herb state (No. 2 and 3). Subsequent succession following moderate to severe fire (No. 4 and 5) in the near-climax (state F1) and climax (state G1) states would be without lodgepole pine (states B2, C3, and D4). The effect of low and moderate severity fires varies by state. A low to moderately severe fire in the pole state (No. 6) would favor Douglas-fir over pine, spruce, and subalpine fir. An open Douglas-fir pole stand would likely result (state C2). Assuming cone-bearing lodgepole in the prefire stand, lodgepole pine regeneration would probably dominate the understory. In the absence of fire, such a stand (state C2) would progress to a mature Douglas-fir forest with a lodgepole understory (state D3). Over time lodgepole would dominate the overstory with a few scattered veteran Douglas-fir, while spruce and subalpine fir would form an understory (state E2). Severe fires would destroy these stands and return site to shrubs and herbs (No. 7 and 8). A cool to moderately severe fire would do little more than set back climax species regeneration and perhaps some understory thinning in the mature Douglas-fir stand (No. 9). A cool fire in the mature lodgepole stand would also have minor impact (No. 10). A moderately severe fire, however, could remove all trees except the more fire-resistant veteran Douglas-fir in the overstory (No. 11).

I. HABITATS SUPPORTING MIXED SPECIES (PSME, PICO, PICEA, & ABLA)

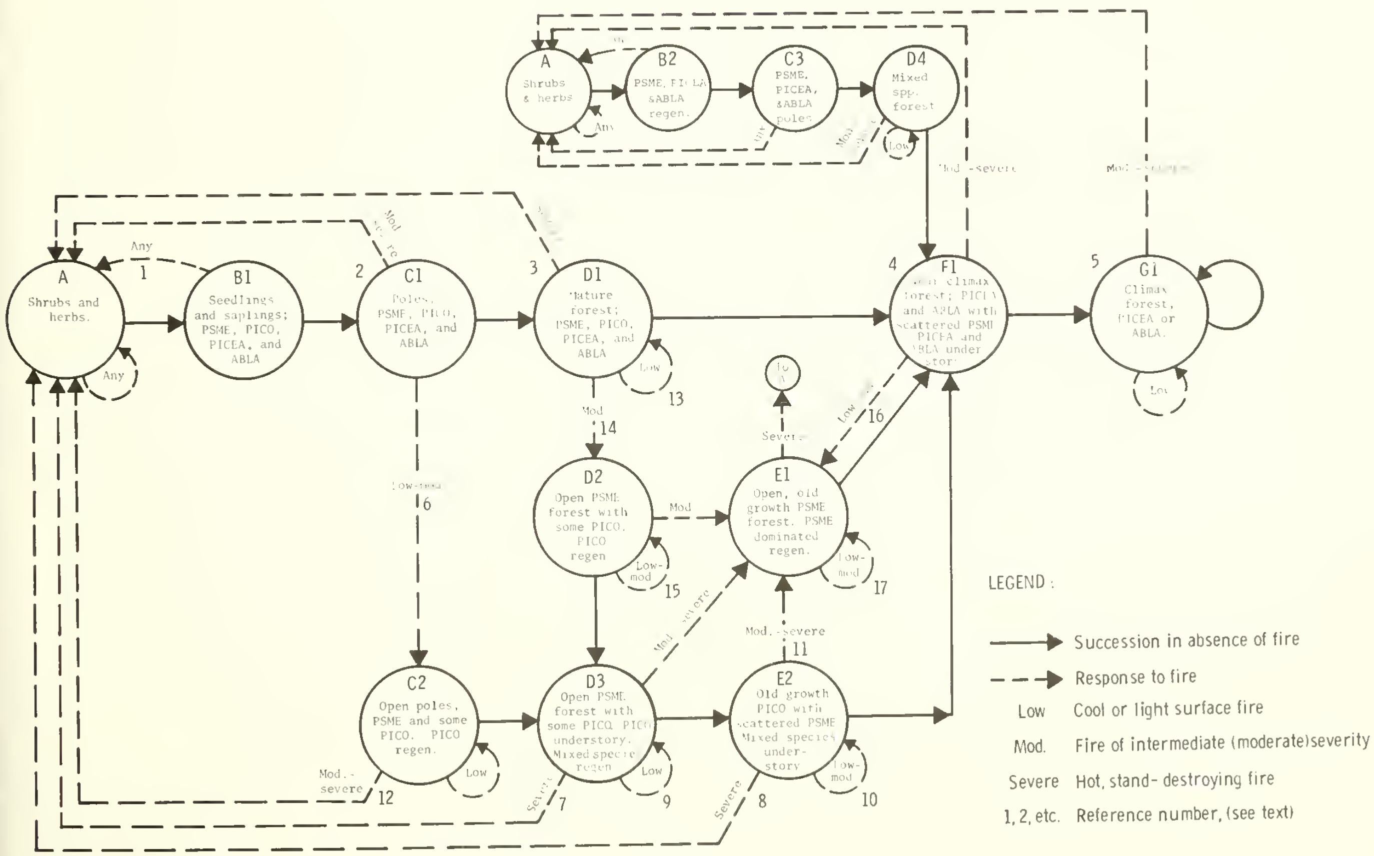



*Figure 34.—Hypothetical fire-related successional pathways for Fire Group Eight habitat types.*

II. ABLA/ CAGE- PSME HABITATS (lodgepole pine & spruce absent)

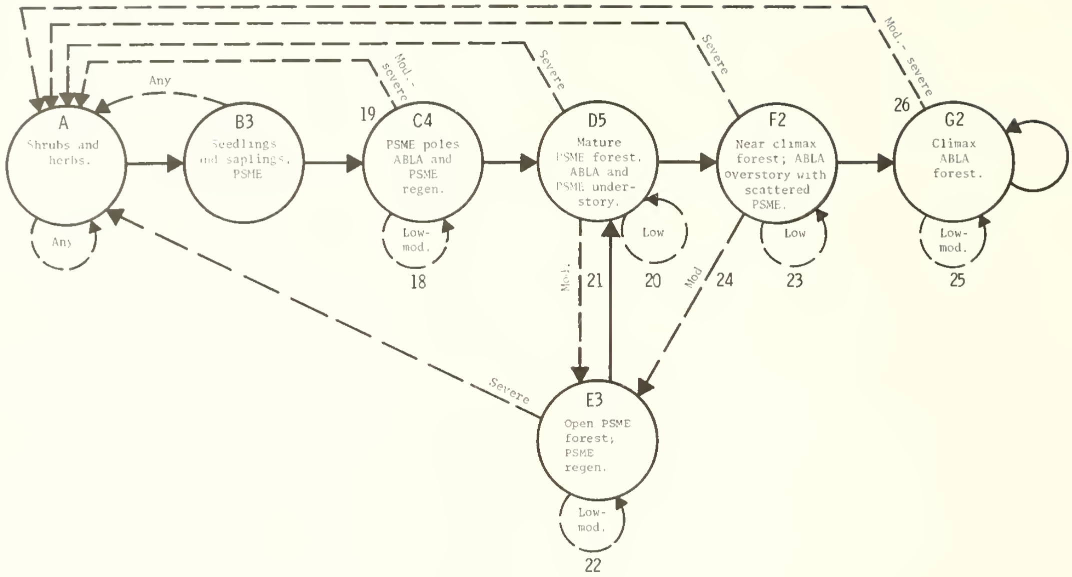



*Figure 34.—(con.)*

III. ABLA/ VASC- THOC HABITATS (Douglas- fir absent)

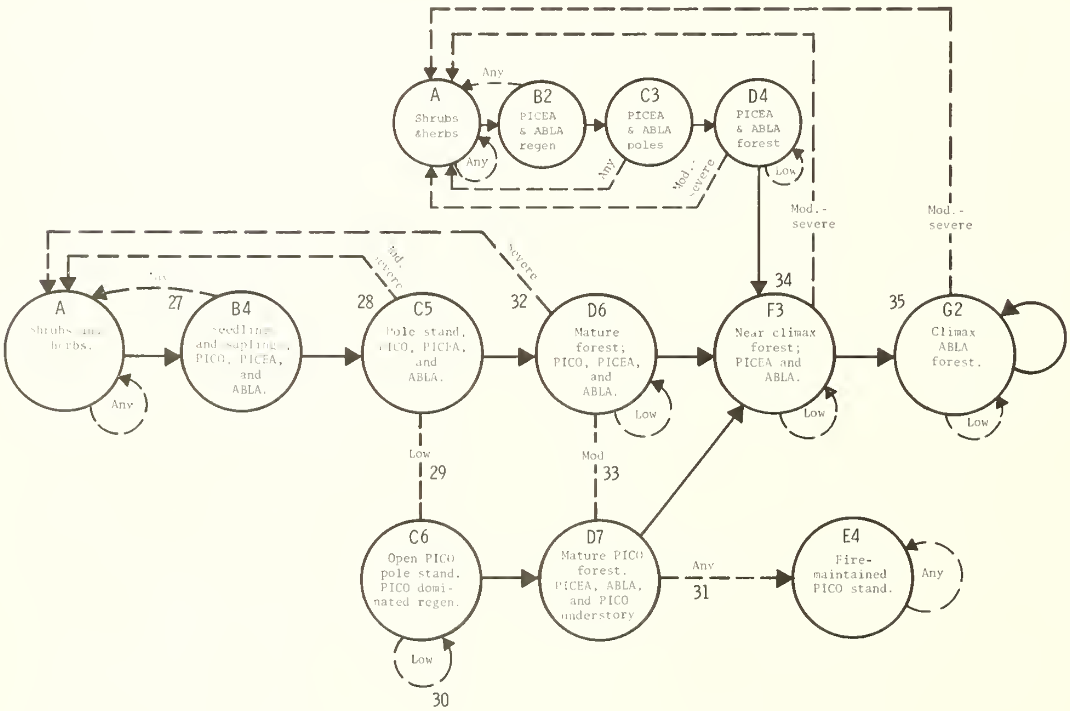



*Figure 34.—(con.)*

In the unlikely event that a fire in the pole state (state C2) is followed by a second moderate to severe fire (No. 12), the stand will revert to shrubs and herbs (state A). It is conceivable that a moderately severe fire could remove lodgepole pine from subsequent succession. For this to occur, lodgepole pine would have to be absent from the prefire stand.

A light surface fire in the mature forest state (state D1) will have little effect on overstory composition (No. 13). Some fir and spruce will be eliminated by a cool fire, but losses should not be widespread. A moderate fire (No. 14), however, could destroy much of the lodgepole, spruce, and subalpine fir leaving an open Douglas-fir overstory (state D2). Periodic cool to moderately severe fire would maintain the open Douglas-fir overstory (No. 15). A similar situation can occur with cool to moderately severe fire in the near-climax forest (No. 16), except that lodgepole regeneration may be absent in the postfire stand (state E1). Cool to moderate fire again would maintain an open Douglas-fir stand (No. 17).

### SUCCESSION WITHOUT LODGEPOLE PINE AND SPRUCE

Fire Group Eight ABLA/CAGE-PSME habitats usually support stands dominated by Douglas-fir. Lodgepole pine and spruce are largely absent (state B3). Douglas-fir pole stands develop in the absence of fire (state C4). Douglas-fir and subalpine fir regeneration develops under such pole stands.

A less than severe fire can periodically remove this regeneration (No. 18). Severe fire will return the site to shrubs and herbs (No. 19). In the absence of fire a mature Douglas-fir forest develops (state D5) with a Douglas-fir and subalpine fir understory. A light surface fire will destroy most of the alpine fir understory and some Douglas-fir, (No. 20). A moderate fire could completely remove the understory (No. 21) leaving an open Douglas-fir forest (state E3). Subsequent low to moderate fire could maintain the open stand condition (No. 22).

Without fire, the mature Douglas-fir forest (state D5) will approach the near-climax state characterized by a subalpine fir overstory with scattered old Douglas-fir trees. Subalpine fir and some Douglas-fir will form the understory. Cool fire will tend to benefit the more fire resistant Douglas-fir trees in the understory (No. 23), and fires of moderate severity (No. 24) could remove all trees except the veteran Douglas-fir in the overstory (state E3).

Given an unlikely long fire-free interval, the climax subalpine fir forest will develop. Low to moderate fire will effect the often dense subalpine fir understory (No. 25), but a moderate to severe fire will destroy the stand (No. 26).

### SUCCESSION WITHOUT DOUGLAS-FIR

Fire Group Eight ABLA/VASC-THOC habitats occur at the upper cold limits of Douglas-fir. Where Douglas-fir does occur on these habitats, it is often frost-stunted. The seedling/sapling state on such habitats will often be populated about equally with lodgepole pine, spruce, and subalpine fir (state B4). Fires occurring in this state will return shrubs and herbs to dominance (No. 27). In the absence of fire, a mixed species pole stand develops (state C5) that is susceptible to destruction by a moderate to severe fire (No. 28). Some lodgepole pine could survive a cool fire (No. 29) resulting in an open pole stand with predominantly lodgepole pine regeneration (state C6). Subsequent cool fire would keep the understory open (No. 30).

In the absence of fire, an open mature lodgepole forest would develop with a spruce and fir understory (state D7). Periodic fire in this state (No. 31) could maintain lodgepole on the site (state E4). In the absence of fire, the more tolerant spruce and fir will eventually attain dominance (state F3).

Without fire the original mixed species pole stand (state C5) will develop into a mature mixed species forest (state D6). A severe to moderately severe fire at this state could destroy the stand (No. 32). A moderate fire (No. 33) could, however, spare some lodgepole. The continued absence of fire will allow a near-climax spruce and subalpine fir forest to develop (state F3) and, theoretically, a climax subalpine fir forest (state G2). Both of these forests would be highly susceptible to severe to moderately severe fire (No. 34 and 35). Succession following such fires would be without lodgepole pine since lodgepole pine is not a member of the near-climax and climax forest.

## Fire Management Considerations

Fire protection is usually an important fire management consideration during severe burning conditions especially where timber production is a management objective. At other times, fires may be of low to moderate severity and result in only moderate damage or no damage to overstory trees, despite the relatively low resistance of many of the species present.

Fire can be used to dispose of logging slash on harvest areas, but broadcast burning for site preparation is often hampered by high duff moisture and scarcity of acceptable burning days during traditional spring and fall prescribed burning periods.

Where timber production is not a management objective, opportunities may exist for implementing fire management prescriptions that allow the use of unscheduled fires. Properly prescribed and managed, such fires can create vegetative mosaics that in turn provide a diversity of wildlife habitats, diverse scenery, and enhanced recreational opportunities. Vegetative mosaics can also reduce the probability of widespread wildfire damage to watershed values.

## FIRE GROUP NINE: MOIST, LOWER SUBALPINE HABITAT TYPES

| ADP code | Habitat type-phase (Pfister and others 1977, Roberts 1980) | Montana forest region (Arno 1979) |
|---|---|---|
| 410 | *Picea/Equisetum arvense* h.t. (PICEA/EQAR), spruce/common horsetail. | North-central, central, southwestern, and south-central. |
| 440 | *Picea/Galium triflorum* h.t. (PICEA/GATR), spruce/sweet-scented bedstraw. | Central, southwestern, and south-central. |
| 621 | *Abies lasiocarpa/Clintonia* h.t.-*Clintonia uniflora* phase (ABLA/CLUN-CLUN), subalpine fir/queencup beadlily-queencup beadlily phase. | North-central. |
| 622 | *Abies lasiocarpa/Clintonia uniflora* h.t.-*Aralia nudicaulis* phase (ABLA/CLUN-ARNU), subalpine fir/queencup beadlily-wild sarsaparilla phase. | North-central. |
| 624 | *Abies lasiocarpa/Clintonia uniflora* h.t.-*Xerophyllum tenax* phase (ABLA/CLUN-XETE), subalpine fir/queencup beadlily-beargrass phase. | North-central. |
| 625 | *Abies lasiocarpa/Clintonia* h.t.-*Menziesia ferruginea* phase (ABLA/CLUN-MEFE), subalpine fir/queencup beadlily-menziesia phase. | North-central. |
| 630 | *Abies lasiocarpa/Galium triflorum* h.t. (ABLA/GATR), subalpine fir/sweetscented bed-bedstraw. | North-central, central, and south-central. |
| 651 | *Abies lasiocarpa/Calamagrostis canadensis* h.t.-*Calamagrostis canadensis* phase (ABLA/CACA-CACA), subalpine fir/bluejoint-bluejoint phase. | Central, southwestern, and south-central. |
| 653 | *Abies lasiocarpa/Calamagrostis canadensis* h.t.-*Galium triflorum* phase (ABLA/CACA-GATR), subalpine fir/bluejoint-sweet-scented bedstraw phase. | Central and southwestern. |
| | *Abies lasiocarpa/Linnaea borealis* h.t. (ABLA/LIBO), subalpine fir/twinflower. | Central (Bearpaw Mountains only). |
| 661 | *Abies lasiocarpa/Linnaea* h.t.-*Linnaea borealis* phase (ABLA/LIBO-LIBO), subalpine fir/twinflower-twinflower phase. | North-central, central, southwestern, and south-central. |
| 670 | *Abies lasiocarpa/Menziesia ferruginea* h.t. (ABLA/MEFE), subalpine fir/menziesia. | North-central, southwestern, south-central. |
| 740 | *Abies lasiocarpa/Alnus sinuata* h.t. (ABLA/ALSI), subalpine fir/Sitka alder. | North-central, southwestern, and south-central. |

Fire Group Nine is a collection of moist and wet lower subalpine habitat types in the spruce and subalpine fir climax series. Group Nine sites typically border streams and adjoin wet meadows. Other typical locations are flat sites with poor drainage, moist bottomlands, benches, northern exposures, and seepage areas on southern exposures. Soils are moist or wet (supersaturated with water) much of the year. Elevations of Group Nine sites range from about 5,800 ft (1 770 m) to 8,200 ft (2 500 m).

Engelmann spruce is usually a major component of seral stands along with lodgepole pine and Douglas-fir. Older stands are usually dominated by subalpine fir and spruce although Douglas-fir and lodgepole may be well represented in the overstory. Notable exceptions to this general pattern of species composition include the ABLA/CACA habitats, which are too wet for Douglas-fir, and the PICEA/EQAR habitats, where spruce is usually the only successful conifer. However, two broadleaf species, paper birch and black cottonwood, may be abundant in seral stands on PICEA/EQAR habitats. Whitebark pine occurs either accidentally or on some habitats as a minor seral component.

Abundant undergrowth occurs on the moist Group Nine habitats. The more common grass and forb species include: red baneberry, wild sarsaparilla, broadleaf arnica, bluejoint, pinegrass, queencup beadlily, common horsetail, sweetscented bedstraw, Richardson's geranium, sidebells pyrola, arrowleaf groundsel, twisted stalk, western round-leaved violet, beargrass, and many other wet-site forbs.

Among the shrubs that occur on more than one habitat type or phase are: Sitka alder, redosier dogwood, twinflower, Utah honeysuckle, smooth menziesia, thimbleberry, blue huckleberry, and grouse whortleberry. Less widespread but abundant on particular habitats are kinnikinnick, bunchberry dogwood, alpine wintergreen, swamp laurel, prickly currant, russet buffaloberry, snowberry, and dwarf huckleberry.

### Forest Fuels

Fire Group Nine fuels are similar to those often encountered in Group Eight. Downed dead woody material on the forest floor averages about 20 tons/acre (about 4.5 kg/m$^2$) but may be much higher.

A large percentage of the downed woody fuel load is material greater than 3 inches (7.6 cm) in diameter (tables 4 and 11, fig. 35). The combination of deep duff and large amounts of dead, rotten fuel can result in a severe surface fire during unusually dry moisture conditions. Where dense understories exist, such fires can easily spread to the tree crowns and destroy the stand. Even if a severe surface fire does not crown, there is a good chance the overstory trees will be killed by cambium heating.

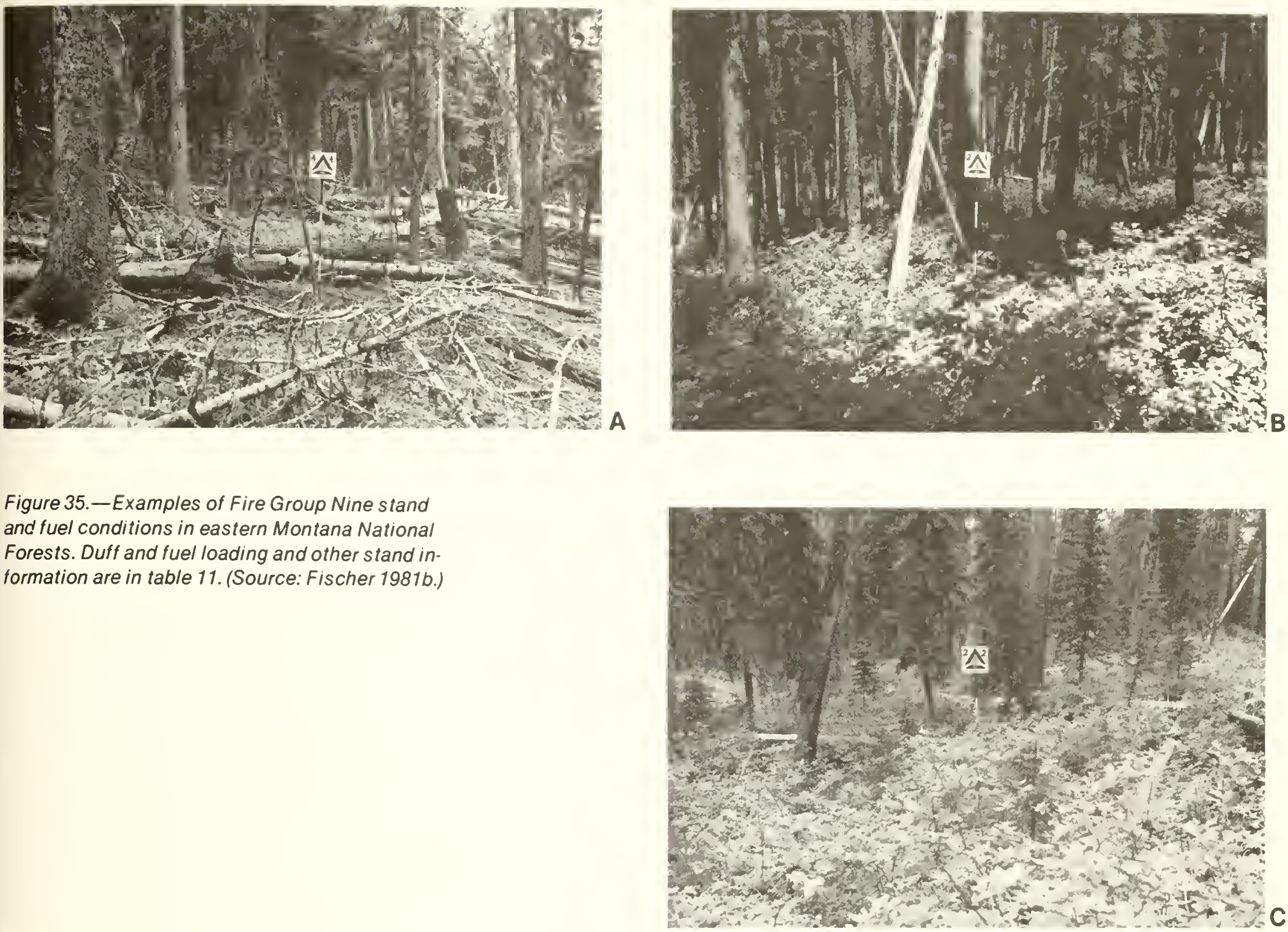


*Figure 35.—Examples of Fire Group Nine stand and fuel conditions in eastern Montana National Forests. Duff and fuel loading and other stand information are in table 11. (Source: Fischer 1981b.)*

**Table 11.**—Fuel loading by size class and duff depth for Fire Group Nine stands shown in figure 35 (source: Fischer 1981b)

| Stand number | Habitat type phase | Age | Duff depth | Size class (inches) | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0-1/4 | 1/4-1 | 1-3 | 3-6 | 6-10 | 10-20 | |
| | | *Years* | *Inches* | *Tons per acre* | | | | | | |
| 21A | ABLA/MEFE | 173[1] | 2.5 | 0.2 | 0.9 | 1.9 | 9.7 | 7.5 | 0 | 20.2 |
| 22A | ABLA/MEFE | 184[2] | 1.9 | 0.5 | 1.8 | 2.0 | 5.9 | 9.4 | 2.9 | 22.5 |
| 44A | PICEA/GATR | 200[3] | 4.9 | 0.4 | 1.8 | 4.1 | 3.0 | 5.5 | 28.7 | 43.5 |

[1]PICEA. Also ABLA 125 yrs and PIAL 160 yrs.
[2]ABLA. Also PIAL 145 yrs and PICO and PICEA 115 yrs.
[3]PICEA and PSME. Understory PICEA are 115 yrs.

Under normal moisture conditions for these sites, a lush undergrowth of shrubs and herbs usually serves as an effective barrier to rapid fire spread (fig. 35).

## Role of Fire

Fire history information for moist, lower subalpine eastside forests is lacking. Mean fire-free intervals are probably less than those of the drier upland sites in Fire Group Eight. The mean fire-free intervals for Fire Group Nine sites (ABLA/CLUN h.t.) at Coram Experimental Forest in northwestern Montana were about 140 years (Sneck [Davis] 1977). Fires at Coram were reported to be small, moderately intense surface fires that occasionally crowned, especially near the ridgetops (Arno 1980). In Kananaskis Provincial Park in Alberta, Canada, stand-replacing fires were found to have occurred at average intervals of 90 years in relatively moist, lower subalpine types composed of subalpine fir, spruce, and lodgepole pine (Hawkes 1979). Relatively long fire-free intervals have been reported for spruce-fir forests on the Medicine Bow National Forest in southwestern Wyoming. Romme and Knight (1981) report average fire-free intervals of 350 to 400 years in moist drainage bottoms, 300 years for the drier lodgepole pine-covered upland sites.

The role of fire on Group Nine habitats east of the Divide in Montana is indicated by stand condition and species composition. The general absence of the spruce and subalpine fir climax condition indicates disturbance by past fires. The codominance of lodgepole pine, Douglas-fir, and spruce on many sites suggests these stands developed on a fire-created mineral seedbed. The abundance of spruce, lodgepole, and Douglas-fir in the overstory of many mature stands suggests the absence of frequent moderate to severe fires after the stand became established. The frequency of light surface fires in Group Nine stands is difficult to surmise. The moist nature of these sites would limit the opportunity for such fires to a brief period during the summer. It seems reasonable to assume that lightning did in fact start such fires and that a certain amount of fuel reduction was accomplished. Left undisturbed, these fires probably flared up occasionally and created openings that favored establishment of seral species.

## Generalized Forest Succession

A general pattern of succession for Fire Group Nine forests is shown in figure 36 (subsequent numbers in this section refer to fig. 36). Secondary succession is initiated by a severe stand-destroying fire in a mature, near-climax, or climax stand (No. 4, 5, and 6). Grass, forbs, and shrubs dominate the burned area until seedlings and saplings become firmly established on the mineral soil seedbed. Lodgepole pine, Douglas-fir, spruce, and to a lesser extent, subalpine fir may be present in the initiating stand. Exceptions to this general pattern include the absence of subalpine fir on PICEA/GATR sites, the absence of all conifers except spruce on PICEA/EQAR sites, and the absence of Douglas-fir on ABLA/CACA sites.

A fire during the seedling/sapling stage is unlikely, but if one occurred the site would revert to the shrub/herb state (No. 1). A fire in the pole stage would likely be of low intensity because of the moisture of the site, lack of hazardous surface fuels, and lushness of the undergrowth. Such a fire would be a thinning fire, favoring the more resistant Douglas-fir (No. 2). A cool fire in a mature stand would also thin out some of the more susceptible stems and reduce accumulated surface fuels (No. 3). It is at this stage that stand replacement fires become likely (No. 4). Such fires usually occur before the near-climax situation is achieved. Should a near-climax condition develop, stand-destroying fire is almost certain before a climax forest develops (No. 5). The theoretical climax situation rarely occurs.

## Successional Pathways

The pattern of tree succession in this group as displayed in figure 37 is relatively simple (subsequent states in this section refer to fig. 37). This simplicity is more a reflection of lack of knowledge than lack of vegetative complexity of this group's communities. Perhaps the most significant information gap has

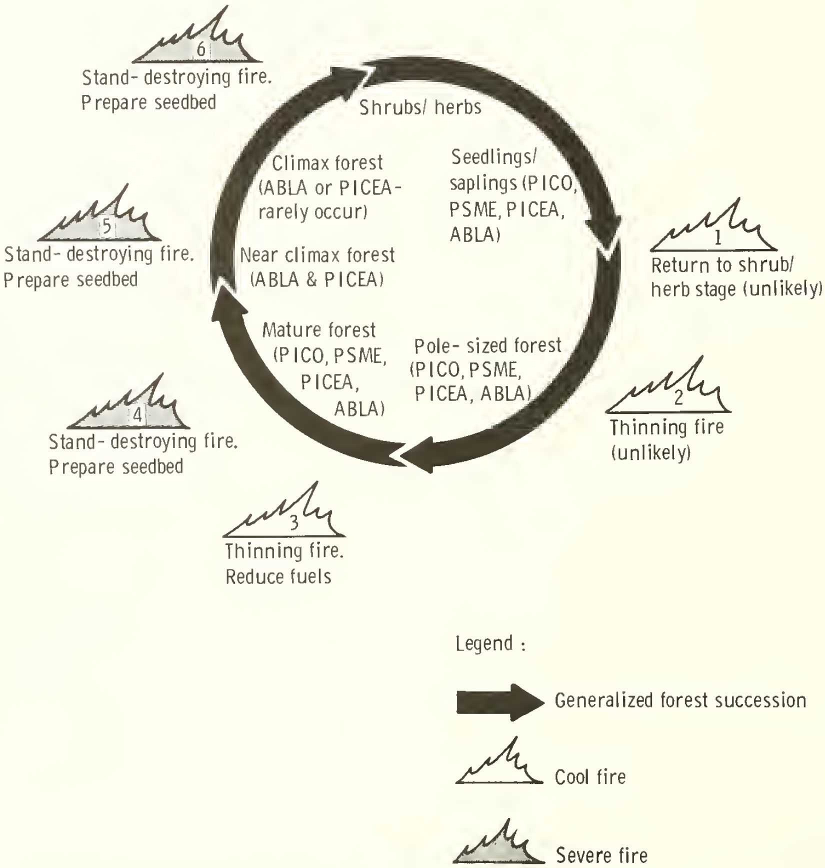



*Figure 36.—Generalized forest succession in Fire Group Nine: moist, lower subalpine habitat types.*

to do with the frequency of occurrence and related effects of cool to moderately severe fires on these moist sites. Figure 37 indicates a minimum impact for cool fire and does not consider a moderately severe fire. Intuitively, one might expect that fires of moderate severity do occur and thin out groups of trees rather than individual trees throughout the stand. If this in fact is the case, the effect of a moderately severe fire is the same as a severe fire, but on a small area within the stand.

The relative simplicity of figure 37 also reflects the assumption that Group Nine sites are as a general rule either too moist to burn or, under conditions of extended summer drought, susceptible to wind-driven crown fire. In simple terms, either the whole thing burns, or it hardly burns at all.

Six states are recognized: shrub/herb, seedling/sapling, pole stand, mature forest, near-climax forest, and the climax forest. Following a stand-destroying fire, shrubs and herbs dominate the site (state A), but seedlings are also becoming established on the mineral soil seedbed. After a relatively brief time, seedlings and then saplings dominate the site (state B). As a general rule, lodgepole pine, Douglas-fir, and spruce will be most abundant, but subalpine fir will also be present and, on some sites, whitebark pine. Lodgepole pine, Douglas-fir, and spruce will jointly dominate most pole stands (state C) and the overstory of the mature forest (state D). It is unlikely that fire will significantly affect succession up to this stage. The possible exception might be if a severe fire sweeps into a young forest from an adjoining area.

The mature forest may have a lush undergrowth of shrubs and herbs along with a developing understory of spruce and subalpine fir. As the stand matures, trees are killed through suppression mortality, mechanical injury (wind and snow), insects and disease, and, perhaps, cool surface fires. Downfall of dead trees results in hazardous fuel accumulation on the forest floor. The development of the understory creates fuel ladders to the overstory crowns. Stand replacement fires become highly probable. The near-climax condition (state E) is probably the most advanced stage of succession attained on these sites. Many Group Nine forests burn catastrophically before this condition is reached. The near-climax condition is characterized by scattered veteran spruce and Douglas-fir that rise above the main spruce-fir overstory. The understory is often dense spruce or fir. The theoretical climax (state F) is either a spruce or a subalpine fir forest, but this is rarely achieved. Light surface fires in states E and F will kill many understory trees, but regeneration will usually be spruce and fir.

## Fire Management Considerations

Fire protection is usually necessary in undisturbed stands during severe burning conditions. This is especially true for areas where timber production is a management objective. At other times, fires may be of low to moderate severity and result in only moderate damage or no damage to overstory trees, despite the relatively low fire resistance of many of the species present. If slash is present, unacceptable tree mortality can result under quite easy burning conditions.

Broadcast burning is an effective method for reducing slash hazard and for preparing seedbeds in clearcuts, but not in partial cuts. Timing of a burn is important. Group Nine habitats are so cool and moist that times when effective broadcast burns can be achieved are limited. The moisture content of the duff must be low enough to allow the fire to bare mineral soil over much of the area. Often, such favorable moisture conditions only occur during the late summer when the threat of wildfire usually discourages managers from conducting prescribed fires.

Burning slash in large windrows or piles can create enough heat to alter the physical structure of the soil. Lower densities and slower growth of conifers on some burned pile and windrow sites can persist for 15 years or more (Vogl and Ryder 1969). Consequently, windrows should be narrow and piles should be small when these methods are used.

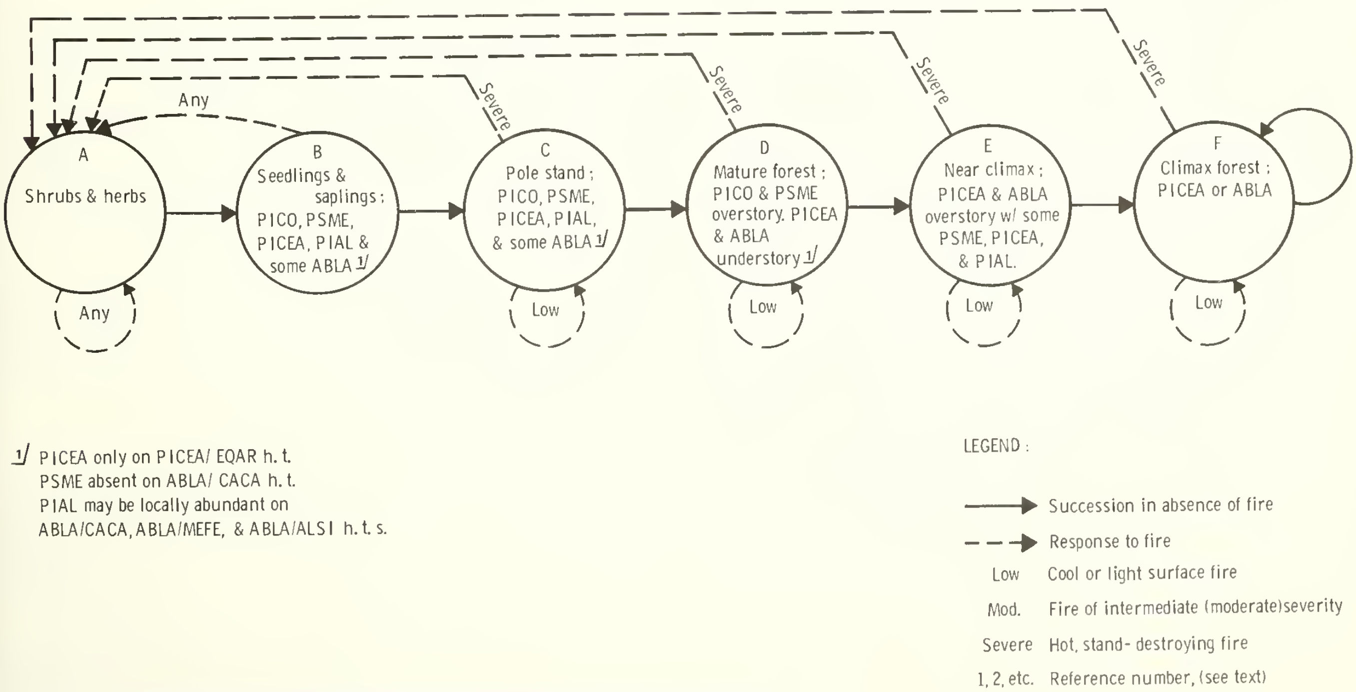



*Figure 37.—Hypothetical fire-related successional pathways for Fire Group Nine habitat types.*

Additional guidelines for fire use for slash disposal and site preparation and silviculture in Group Nine stands are provided by Roe and others (1970). This excellent reference should be consulted before planning fire use in these habitats.

Slash disposal plans should consider the need for some residues to remain on the site for nutrient cycling and as a source of shade for successful seedling development.

The often complex structure of subalpine forests reflects their fire history. These forests are what they are partly because of past patchy or uneven burns and partly because of their climate and soils. Their natural development has not, as a general rule, been affected by past fire suppression policies (Habeck and Mutch 1973). Management objectives for these habitat types are often oriented toward nonconsumptive use. These types usually have high watershed and big game sanctuary values. Many of the areas that contain these habitat types are roadless and may be destined to remain so. Many are in designated wilderness areas. Consequently, the appropriate fire management policy may be one that allows certain fires at certain times to burn as prescribed fires according to a predetermined fire management prescription. Often this policy must be constrained because of air quality considerations and because of the occasional threat of long distance spotting or wind-driven crown fires.

## FIRE GROUP TEN: COLD, MOIST UPPER SUBALPINE AND TIMBERLINE HABITAT TYPES

| ADP code | Habitat type-phase (Pfister and others 1977, Roberts 1980) | Montana forest region (Arno 1979) |
|---|---|---|
| | Upper Subalpine | |
| 462 | *Picea/Senecio streptanthifolius* h.t.-*Picea* phase (PICEA/SEST-PICEA), spruce/cleftleaf groundsel-spruce phase. | Central. |
| | *Picea/Juniperus communis* h.t. (PICEA/JUCO), spruce/common juniper. | Central (Bearpaw Mountains only). |
| 810 | *Abies lasiocarpa/Ribes montigenum* h.t. (ABLA/RIMO), subalpine fir/mountain gooseberry. | Southwestern and south-central. |
| 820 | *Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium* h.t. (ABLA-PIAL/VASC), subalpine fir-whitebark pine/grouse whortleberry. | North-central, central, south-central, southwestern, and south-central. |
| 831 | *Abies lasiocarpa/Luzula hitchcockii* h.t.-*Vaccinium scoparium* phase (ABLA/LUHI-VASC), subalpine fir/smooth woodrush-grouse whortleberry phase. | North-central and southwestern. |
| 832 | *Abies lasiocarpa/Luzula hitchcockii* h.t.-*Menziesia ferruginea* phase (ABLA/LUHI-MEFE), subalpine fir/smooth woodrush-menziesia phase. | North-central. |
| | *Abies lasiocarpa/Juniperus communis* h.t. (ABLA/JUCO), subalpine fir/common juniper. | Central (Bearpaw Mountains only). |
| | Timberline | |
| 850 | *Pinus albicaulis-Abies lasiocarpa* h.t.'s (PIAL-ABLA h.t.'s), whitebark pine-subalpine fir. | North-central, central, southwestern, and south-central. |
| 860 | *Larix lyallii-Abies lasiocarpa* h.t.'s (LALY-ABLA h.t.'s) alpine larch-subalpine fir. | Southwestern. |
| 870 | *Pinus albicaulis* h.t.'s (PIAL h.t.'s) whitebark pine. | Central, southwestern, and south-central. |

Fire Group Ten consists of high elevation forests near and at the timberline. All the stands lie above the climatic limits of Douglas-fir and many stands are above the cold limits of limber pine and lodgepole pine. Subalpine fir is the indicated climax in all but one of the upper subalpine habitat types. The exception is the PICEA/SEST-PICEA h.t. where Engelmann spruce is the indicated climax and the only conifer. Whitebark pine is usually well represented in this group's upper subalpine habitat types. Engelmann spruce is also a major long-lived seral species. Lodgepole pine may occur on some upper subalpine sites.

Timberline forests are composed of alpine larch, whitebark pine, Engelmann spruce, and subalpine fir. Trees characteristically grow in groups with open areas in between. Timberline habitat types are named for their tree component, not for the indicated climax species.

Undergrowth in this group is usually sparse and at timberline it is highly variable. Shrubs that may occur on Group Ten sites include smooth menziesia, red and yellow mountain heaths, white rhododendron, mountain gooseberry, grouse whortleberry, and common juniper.

Common forbs are broadleaf arnica, ballhead sandwort, and slender hawkweed. Grass and grasslike vegetation includes Ross sedge, Idaho fescue, Parry rush, smooth woodrush, and beargrass.

### Forest Fuels

Fire Group Ten habitats are characterized by relatively heavy loadings of large diameter downed and dead woody fuels. Fuel inventory data from eastside forests show an average of about 2 tons/acre (0.45 kg/$m^2$) of small diameter materials, 0.25 to 3 inches (0.6 to 7.6 cm), and about 9 tons/acre (about 2 kg/$m^2$) of large material over 3 inches (7.6 cm) in diameter (table 4). These figures agree quite well with those reported for Group Ten sites in the Selway-Bitterroot Wilderness

(Davis and others 1980). Average fuel loadings on some habitat types may be twice the Fire Group average (fig. 2).

The downed and dead woody fuel loadings in Group Ten stands often take the form of scattered large diameter downfall resulting from wind and snow breakage, windthrow, and insect- and disease-caused mortality. Such heavy fuels do not necessarily reflect a serious fire hazard. The mitigating effects of the normally cool, moist site, the very short fire season, and the usually sparse and often discontinuous nature of fine surface fuels, must be considered when evaluating overall fire potential. Examples of Group Ten fuel and stand conditions are shown in figure 38.


A


B


C


D


E

*Figure 38.—Examples of fuel and stand conditions in some Fire Group Ten habitats. (A) A PIAL-ABLA h.t. with scattered downed woody fuel and flammable thicket of fir. Snags shown will eventually add to surface fuel loads. (B) A PIAL h.t. with sparse surface fuels and clusters of whitebark pine. (C) An ABLA/LUHI h.t. showing lush surface vegetation and low-hanging branches. (D) An ABLA/LUHI-MEFE h.t. with heavy dead woody fuels intermingled with dense live fuels. (E) A typical LALY-ABLA habitat.*

## Role of Fire

Fire is secondary to site factors (climate and soil) as an influence on forest development on these sites. The cold, moist, rocky, snowbound, unproductive, and otherwise fire-resistant environment that makes up much of this group not only makes fires infrequent but severely limits their extent. Lightning does ignite fires, but the paucity of continuous fine surface fuels coupled with the rain that commonly accompanies thunderstorms effectively limits fire spread and severity. Fire frequencies ranging from 35 to 300 years have been reported for individual sites (Romme 1980). Such figures are difficult to interpret because a fire may involve only one or two trees in a stand. For this reason the concept of fire frequency does not apply well in upper subalpine and timberline sites.

In the more continuous forests of this group, the most pronounced fire effect is to produce stand-replacing fires at long intervals, perhaps 200 years or more. Stand-destroying fires in Group Ten are most likely to occur during extended drought conditions when severe wind-driven crown fires develop in the forests below and burn into the upper subalpine and timberline forests. Vegetation recovery following such fires is usually slow because of the extremely short growing season and cold climate.

## Generalized Forest Succession

In Group Ten habitats, secondary succession begins with a mixture of herbs and shrubs probably including some conifer seedlings (fig. 38). It is likely that herbaceous plants will dominate for an extended period. Fire may initiate secondary succession, but it is unlikely that it has a role in maintaining it. Physical disruption of the stand by snow and wind, rock slides, and snow and talus slippage is more important on moist sites and north slopes than fire in maintaining early stages of succession.

It takes a long time before conifers dominate some Group Ten sites, perhaps 100 years. It may take another 100 years before a mature forest exists. It is unlikely that fuel or stand conditions will support a fire of any consequence during this period. Surface fires do occur, especially in whitebark pine stands on south slopes and ridges. Such fires act as underburns, reducing fuels and killing some overstory trees. Severe fires may occur over small areas, but their effect will usually be limited to the creation of vegetative mosaics. Eventually the mature forest will begin to break up under the impact of wind and snow breakage, windthrow, insect-and disease-related mortality, and senescence. Stand-destroying fires, especially those that invade from lower elevation forests, become a possibility during extended drought.

Without disturbance, the mature trees will progress into a climax stand. This advance successional stage requires decades, possibly two or three centuries. Low to moderate severity fires rarely have a significant impact on a mature stand because of the open structure and lack of continuous fine woody fuels; however, severe fires that enter the crowns and kill the cambium of trees return the site to the early successional stages (fig. 39).

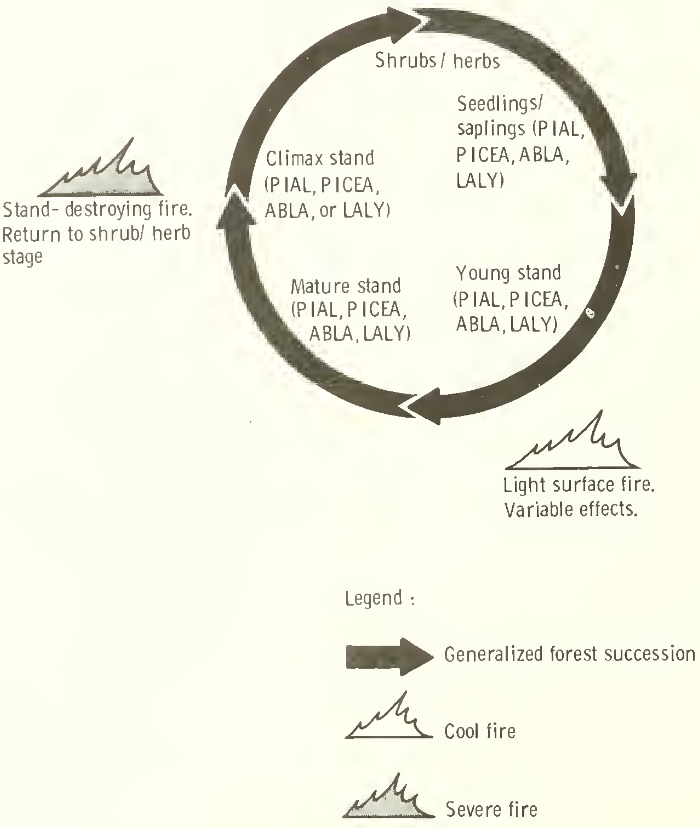



*Figure 39.—Generalized forest succession in Fire Group Ten: cold, moist upper subalpine and timberline habitat types. Low-severity lightning fires may occur at any stage with little effect on succession.*

## Successional Pathways

A simple succession pattern postulated for Fire Group Ten is shown in figure 40 (subsequent states and numbers in this section refer to fig. 40). Shrubs and herbs are the initial stage of succession following disturbance (state A). In the unlikely event that a fire occurred in this state, the effect would be minimal (No. 1). Conifer regeneration will dominate the site after an extended regeneration period (state B). Again, a fire during this stage is unlikely, and if one occurs it will be low intensity and have little effect on vegetative succession (No. 2). A mature forest will develop after a long time (state C). Lightning fires may ignite individual trees and spread to adjoining trees (No. 3). The effect of such cool fires may be to create small openings in stands. Over time, a mosaic of successional stages may result. A severe fire could occur at this stage of succession (No. 4), especially one that originates in the lower elevation and burns into the Group Ten stand. Severe stand-replacing fires are also common in high ridgetop stands during lightning storms. Such fires revert the site to shrubs and herbs. If a major disturbance does not interfere, succession will continue until some stable state or climax is achieved (state D). Cool fires will have little effect on this state (No. 5). A severe stand-destroying fire will revert the site to the herbaceous state (No. 6).

## Fire Management Considerations

Timber production is rarely an important management objective in this group's habitat types. Most of these areas are managed as watersheds, natural areas, and sanctuaries for wildlife. For example, whitebark pine forests have been found to be important food producers for jays, bears, squirrels, deer, and elk (Forcella and Weaver 1980). Most are roadless and many are in wilderness areas. Fire is an infrequent visitor and, when it does occur, damage in terms of management objectives is generally slight. These sites are, however, often fragile and can easily be damaged by modern, mechanized firefighting equipment.

The primary fire management considerations for Group Ten habitats should be the development of prescriptions that allow fire to more nearly play its natural role.

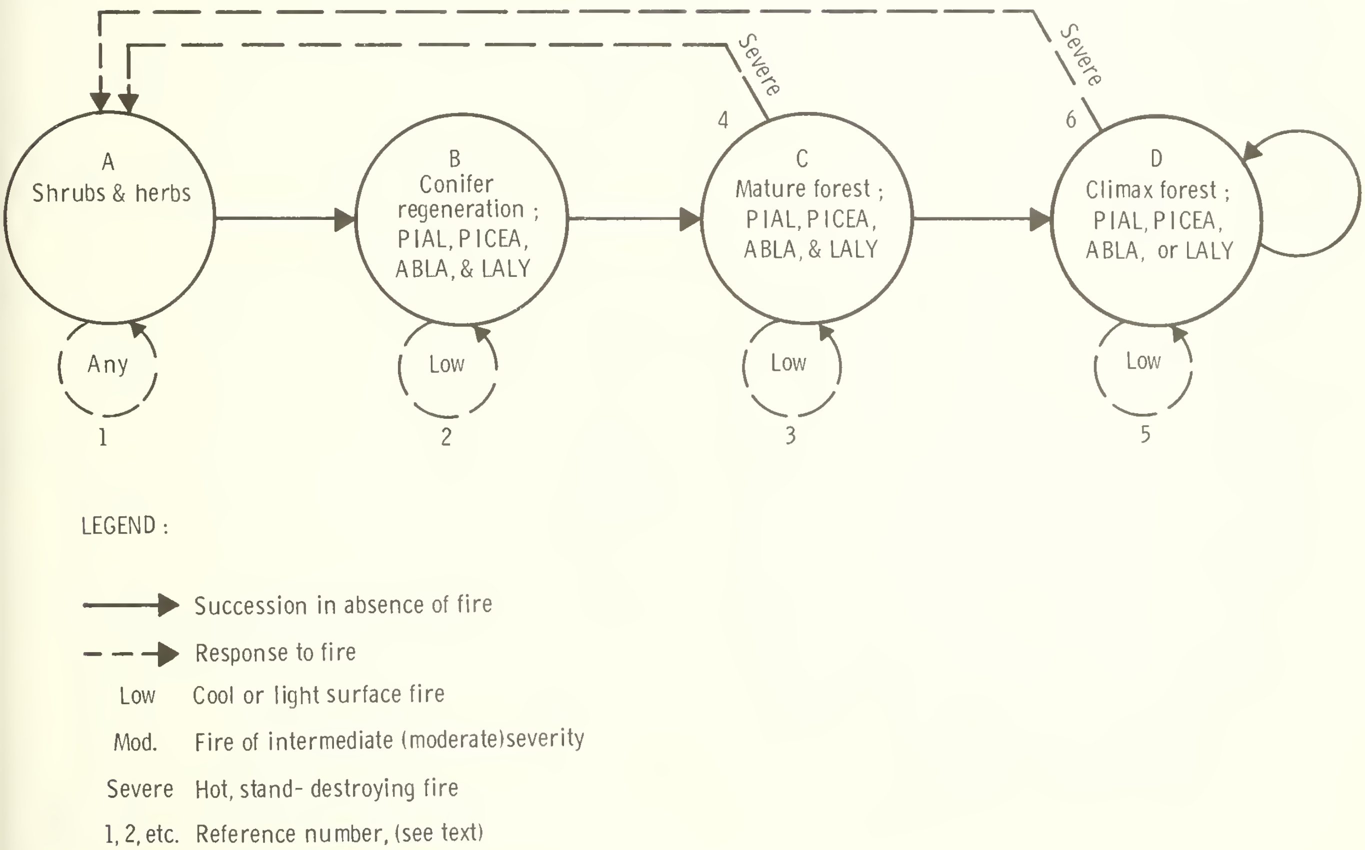



*Figure 40.—Hypothetical fire-related successional pathways for Fire Group Ten habitat types.*

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# APPENDIX A. FOREST HABITAT TYPES OCCURRING EAST OF THE CONTINENTAL DIVIDE IN MONTANA

| ADP code[1] | Abbreviation | Habitat types and phases: Scientific names | Habitat types and phases: Common names |
|---|---|---|---|
| I. BEAVERHEAD, CUSTER, DEERLODGE, GALLATIN, HELENA, AND LEWIS AND CLARK NATIONAL FORESTS[2] | | | |
| 010 | SCREE | | |
| 000 | | PINUS FLEXILIS CLIMAX SERIES | |
| 040 | PIFL/AGSP h.t. | Pinus flexilis/Agropyron spicatum h.t. | limber pine/bluebunch wheatgrass |
| 050 | PIFL/FEID h.t. | Pinus flexilis/Festuca idahoensis h.t. | limber pine/Idaho fescue |
| 051 | -FEID phase | -Festuca idahoensis phase | -Idaho fescue phase |
| 052 | -FESC phase | -Festuca scabrella phase | -rough fescue phase |
| 070 | PIFL/JUCO h.t. | Pinus flexilis/Juniperus communis h.t. | limber pine/common juniper |
| | | PINUS PONDEROSA CLIMAX SERIES | |
| 110 | PIPO/AND h.t.[2] | Pinus ponderosa/Andropogon spp. h.t. | ponderosa pine/bluestem |
| 130 | PIPO/AGSP h.t. | Pinus ponderosa/Agropyron spicatum h.t. | ponderosa pine/bluebunch wheatgrass |
| 140 | PIPO/FEID h.t. | Pinus ponderosa/Festuca idahoensis h.t. | ponderosa pine/Idaho fescue |
| 141 | -FEID phase | -Festuca idahoensis phase | -Idaho fescue phase |
| 142 | -FESC phase | -Festuca scabrella phase | -rough fescue phase |
| 160 | PIPO/PUTR h.t. | Pinus ponderosa/Purshia tridentata h.t. | ponderosa pine/bitterbrush |
| 161 | -AGSP phase | -Agropyron spicatum phase | -bluebunch wheatgrass phase |
| 162 | -FEID phase | -Festuca idahoensis phase | -Idaho fescue phase |
| 170 | PIPO/SYAL h.t. | Pinus ponderosa/Symphoricarpos albus h.t. | ponderosa pine/snowberry |
| 171 | -SYAL phase | -Symphoricarpos albus phase | -snowberry phase |
| 172 | -BERE phase | -Berberis repens phase | -creeping Oregon grape phase |
| 180 | PIPO/PRVI h.t. | Pinus ponderosa/Prunus virginiana h.t. | ponderosa pine/chokecherry |
| 181 | -PRVI phase | -Prunus virginiana phase | -chokecherry phase |
| 182 | -SHCA phase | -Shepherdia canadensis phase | -buffaloberry phase |
| 200 | | PSEUDOTSUGA MENZIESII CLIMAX SERIES | |
| 210 | PSME/AGSP h.t. | Pseudotsuga menziesii/Agropyron spicatum h.t. | Douglas-fir/bluebunch wheatgrass |
| 220 | PSME/FEID h.t. | Pseudotsuga menziesii/Festuca idahoensis h.t. | Douglas-fir/Idaho fescue |
| 230 | PSME/FESC h.t. | Pseudotsuga menziesii/Festuca scabrella h.t. | Douglas-fir/rough fescue |
| 250 | PSME/VACA h.t. | Pseudotsuga menziesii/Vaccinium caespitosum h.t. | Douglas-fir/dwarf huckleberry |
| 260 | PSME/PHMA h.t. | Pseudotsuga menziesii/Physocarpus malvaceus h.t. | Douglas-fir/ninebark |
| 261 | -PHMA phase | -Physocarpus malvaceus phase | -ninebark phase |
| 280 | PSME/VAGL h.t. | Pseudotsuga menziesii/Vaccinium globulare h.t. | Douglas-fir/blue huckleberry |
| 281 | -VAGL phase | -Vaccinium globulare phase | -blue huckleberry |
| 282 | -ARUV phase | -Arctostaphylos uva-ursi phase | -kinnikinnick phase |
| 283 | -XETE phase | -Xerophyllum tenax phase | -beargrass phase |
| 290 | PSME/LIBO h.t. | Pseudotsuga menziesii/Linnaea borealis h.t. | Douglas-fir/twinflower |
| 291 | -SYAL phase | -Symphoricarpos albus phase | -snowberry phase |
| 292 | -CARU phase | -Calamagrostis rubescens phase | -pinegrass phase |
| 293 | -VAGL phase | -Vaccinium globulare phase | -blue huckleberry phase |
| 310 | PSME/SYAL h.t. | Pseudotsuga menziesii/Symphoricarpos albus h.t. | Douglas-fir/snowberry |
| 311 | -AGSP phase | -Agropyron spicatum phase | -bluebunch wheatgrass phase |
| 312 | -CARU phase | -Calamagrostis rubescens phase | -pinegrass phase |
| 313 | -SYAL phase | -Symphoricarpos albus phase | -snowberry phase |
| 320 | PSME/CARU h.t. | Pseudotsuga menziesii/Calamagrostis rubescens h.t. | Douglas-fir/pinegrass |
| 321 | -AGSP phase | -Agropyron spicatum phase | -bluebunch wheatgrass phase |
| 323 | -CARU phase | -Calamagrostis rubescens phase | -pinegrass phase |
| 324 | -PIPO phase | -Pinus ponderosa phase | -ponderosa pine phase |
| 330 | PSME/CAGE h.t. | Pseudotsuga menziesii/Carex geyeri h.t. | Douglas-fir/elk sedge |
| 340 | PSME/SPBE h.t. | Pseudotsuga menziesii/Spiraea betulifolia h.t. | Douglas-fir/white spiraea |
| 350 | PSME/ARUV h.t. | Pseudotsuga menziesii/Arctostaphylos uva-ursi h.t. | Douglas-fir/kinnikinnick |
| 360 | PSME/JUCO h.t. | Pseudotsuga menziesii/Juniperus communis h.t. | Douglas-fir/common juniper |
| 370 | PSME/ARCO h.t. | Pseudotsuga menziesii/Arnica cordifolia h.t. | Douglas-fir/heartleaf arnica |
| 380 | PSME/SYOR h.t.[2] | Pseudotsuga menziesii/Symphoricarpos oreophilus h.t. | Douglas-fir/mountain snowberry |

*(con.)*

| ADP code[1] | Abbreviation | Habitat types and phases: Scientific names | Habitat types and phases: Common names |
|---|---|---|---|
| 400 | | PICEA CLIMAX SERIES | |
| 410 | PICEA/EQAR h.t. | Picea/Equisetum arvense h.t. | spruce/common horsetail |
| 430 | PICEA/PHMA h.t. | Picea/Physocarpus malvaceus h.t. | spruce/ninebark |
| 440 | PICEA/GATR h.t. | Picea/Galium triflorum h.t. | spruce/sweetscented bedstraw |
| 450 | PICEA/VACA h.t. | Picea/Vaccinium caespitosum h.t. | spruce/dwarf huckleberry |
| 460 | PICEA/SEST h.t. | Picea/Senecio streptanthifolius h.t. | spruce/cleft-leaf groundsel |
| 461 | -PSME phase | -Pseudotsuga menziesii phase | -Douglas-fir phase |
| 462 | -PICEA phase | -Picea phase | -spruce phase |
| 470 | PICEA-LIBO h.t. | Picea/Linnaea borealis h.t. | spruce/twinflower |
| 480 | PICEA-SMST h.t. | Picea/Smilacina stellata h.t. | spruce/starry Solomon's seal |
| 600 | | ABIES LASIOCARPA CLIMAX SERIES | |
| 700 | | Lower subalpine h.t.'s | |
| 620 | ABLA/CLUN h.t. | Abies lasiocarpa/Clintonia uniflora h.t. | subalpine fir/queencup beadlily |
| 621 | -CLUN phase | -Clintonia uniflora phase | -queencup beadlily phase |
| 622 | -ARNU phase | -Aralia nudicaulis phase | -wild sarsaparilla phase |
| 624 | -XETE phase | -Xerophyllum tenax phase | -beargrass phase |
| 625 | -MEFE phase | -Menziesia ferruginea phase | -menziesia phase |
| 640 | ABLA/VACA h.t. | Abies lasiocarpa/Vaccinium caespitosum h.t. | subalpine fir/dwarf huckleberry |
| 650 | ABLA/CACA h.t. | Abies lasiocarpa/Calamagrostis canadensis h.t. | subalpine fir/bluejoint |
| 651 | -CACA | -Calamagrostis canadensis phase | -bluejoint |
| 653 | -GATR phase | -Galium triflorum phase | -sweetscented bedstraw phase |
| 654 | -VACA phase | -Vaccinium caespitosum phase | -dwarf huckleberry phase |
| 660 | ABLA/LIBO h.t. | Abies lasiocarpa/Linnaea borealis h.t. | subalpine fir/twinflower |
| 661 | -LIBO phase | -Linnaea borealis phase | -twinflower |
| 663 | -VASC phase | -Vaccinium scoparium phase | -grouse whortleberry phase |
| 670 | ABLA/MEFE h.t. | Abies lasiocarpa/Menziesia ferruginea h.t. | subalpine fir/menziesia |
| 690 | ABLA/XETE h.t. | Abies lasiocarpa/Xerophyllum tenax h.t. | subalpine fir/beargrass |
| 691 | -VAGL phase | -Vaccinium globulare phase | -blue huckleberry phase |
| 692 | -VASC phase | -Vaccinium scoparium phase | -grouse whortleberry phase |
| 720 | ABLA/VAGL | Abies lasiocarpa/Vaccinium globulare h.t. | subalpine fir/blue huckleberry |
| 730 | ABLA/VASC h.t. | Abies lasiocarpa/Vaccinium scoparium h.t. | subalpine fir/grouse whortleberry |
| 731 | -CARU phase | -Calamagrostis rubescens phase | -pinegrass phase |
| 732 | -VASC phase | -Vaccinium scoparium phase | -grouse whortleberry phase |
| 733 | -THOC phase | -Thalicturm occidentale phase | -western meadowrue phase |
| 740 | ABLA/ALSI h.t. | Abies lasiocarpa/Alnus sinuata h.t. | subalpine fir/Sitka alder |
| 750 | ABLA/CARU h.t. | Abies lasiocarpa/Calamagrostis rubescens h.t. | subalpine fir/pinegrass |
| 770 | ABLA/CLPS h.t. | Abies lasiocarpa/Clematis pseudoalpina h.t. | subalpine fir/virgin's bower |
| 780 | ABLA/ARCO h.t. | Abies lasiocarpa/Arnica cordifolia h.t. | subalpine fir/heartleaf arnica |
| 790 | ABLA/CAGE h.t. | Abies lasiocarpa/Carex geyeri h.t. | subalpine fir/elk sedge |
| 791 | -CAGE phase | -Carex geyeri phase | -elk sedge phase |
| 792 | -PSME phase | -Pseudotsuga menziesii phase | -Douglas-fir phase |
| | | Upper subalpine h.t.'s | |
| 810 | ABLA/RIMO h.t. | Abies lasiocarpa/Ribes montigenum h.t. | subalpine fir/mountain gooseberry |
| 820 | ABLA-PIAL/VASC h.t. | Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium h.t. | subalpine fir-whitebark pine/grouse whortleberry |
| 830 | ABLA/LUHI h.t. | Abies lasiocarpa/Luzula hitchcockii h.t. | subalpine fir/smooth wood-rush |
| 831 | -VASC | -Vaccinium scoparium phase | -grouse whortleberry phase |
| 832 | -MEFE phase | -Menziesia ferruginea phase | -menziesia phase |
| 890 | | Timberline h.t.'s. | |
| 850 | PIAL-ABLA h.t.'s. | Pinus albicaulis-Abies lasiocarpa h.t.'s. | whitebark pine-subalpine fir |
| 860 | LALY-ABLA h.t.'s. | Larix lyallii-Abies lasiocarpa h.t.'s. | alpine larch-subalpine fir |
| 870 | PIAL h.t.'s. | Pinus albicaulis h.t.'s. | whitebark pine |

*(con.)*

Appendix A. (con.)

| ADP code[1] | Abbreviation | Habitat types and phases: Scientific names | Common names |
|---|---|---|---|
| 900 | | PINUS CONTORTA CLIMAX SERIES | |
| 910 | PICO/PUTR h.t. | Pinus contorta/Purshia tridentata h.t. | lodgepole pine/bitterbrush |
| 920 | PICO/VACA c.t. | Pinus contorta/Vaccinium caespitosum c.t. | lodgepole pine/twinflower |
| 930 | PICO/LIBO c.t. | Pinus contorta/Linnaea borealis c.t. | lodgepole pine/twinflower |
| 940 | PICO/VASC c.t. | Pinus contorta/Vaccinium scoparium c.t. | lodgepole pine/grouse whortleberry |
| 950 | PICO/CARU c.t. | Pinus contorta/Calamagrostis rubescens c.t. | lodgepole pine/pinegrass |
| II. BEARPAW MOUNTAINS[3] | | | |
| | | PINUS PONDEROSA CLIMAX SERIES | |
| | PIPO/AGSP h.t. | Pinus ponderosa/Agropyron spicatum h.t. | ponderosa pine/bluebunch wheatgrass |
| | PIPO/FEID h.t. | Pinus ponderosa/Festuca idahoensis h.t. | ponderosa pine/Idaho fescue |
| | -FESC phase | -Festuca scabrella phase | -rough fescue phase |
| | PIPO/AMAL h.t. | Pinus ponderosa/Amelanchier alnifolia h.t. | ponderosa pine/serviceberry |
| | | PSEUDOTSUGA MENZIESII CLIMAX SERIES | |
| | PSME/SYOC h.t. | Pseudotsuga menziesii/Symphoricarpos occidentalis h.t. | Douglas-fir/western snowberry |
| | -CHVI phase | -Chrysopsis villosa phase | -hairy golden aster phase |
| | PSME/AMAL h.t. | Pseudotsuga menziesii/Amelanchier alnifolia h.t. | Douglas-fir/serviceberry |
| | PSME/VICA h.t. | Pseudotsuga menziesii/Viola canadensis h.t. | Douglas-fir/Canadian violet |
| | PSME/LIBO h.t. | Pseudotsuga menziesii/Linnaea borealis h.t. | Douglas-fir/twinflower |
| | -CARU phase | -Calamagrostis rubescens phase | -pinegrass phase |
| | PSME/COCA h.t. | Pseudotsuga menziesii/Cornus canadensis h.t. | Douglas-fir/bunchberry dogwood |
| | -LIBO phase | -Linnaea borealis phase | -twinflower phase |
| | -VAMY phase | -Vaccinium myrtillus phase | -Myrtle whortleberry phase |
| | | PICEA CLIMAX SERIES | |
| | PICEA/JUCO s.t. | Picea/Juniperus communis s.t. | spruce/common juniper |
| | PICEA/LIBO h.t. | Picea/Linnaea borealis h.t. | spruce/twinflower |
| | | ABIES LASIOCARPA CLIMAX SERIES | |
| | ABLA/JUCO s.t. | Abies lasiocarpa/Juniperus communis s.t. | subalpine fir/common juniper |
| | ABLA/LIBO h.t. | Abies lasiocarpa/Linnaea borealis h.t. | subalpine fir/twinflower |
| III. LITTLE ROCKY MOUNTAINS[3] | | | |
| | | PONDEROSA PINE CLIMAX SERIES | |
| | PIPO/JUHO h.t. | Pinus ponderosa/Juniperus horizontalis h.t. | ponderosa pine/horizontal juniper |
| | PIPO/SYOC h.t. | Pinus ponderosa/Symphoricarpos occidentalis h.t. | ponderosa pine/western snowberry |
| | PIPO/ARUV h.t. | Pinus ponderosa/Arctostaphylos uva-ursi h.t. | ponderosa pine/kinnikinnick |
| | PIPO/BERE h.t. | Pinus ponderosa/Berberis repens h.t. | ponderosa pine/creeping holly grape |
| | | PINUS CONTORTA CLIMAX SERIES | |
| | PICO/JUCO h.t. | Pinus contorta/Juniperus communis h.t. | lodgepole pine/common juniper |
| | PICO/LIBO h.t. | Pinus contorta/Linnaea borealis h.t. | lodgepole pine/twinflower |
| | | PSEUDOTSUGA MENZIESII CLIMAX SERIES | |
| | PSME/SYOC h.t. | Pseudotsuga menziesii/Symphoricarpos occidentalis h.t. | Douglas-fir/western snowberry |
| | -SHCA phase | -Shepherdia canadensis phase | -russet buffaloberry phase |
| | PSME/ARUV h.t. | Pseudotsuga menziesii/Arctostaphylos uva-ursi h.t. | Douglas-fir/kinnikinnick |
| | PSME/BERE h.t. | Pseudotsuga menziesii/Berberis repens h.t. | Douglas-fir/creeping holly grape |
| | -ARUV phase | -Arctostophylos uva-ursi phase | -kinnikinnick phase |
| | -BERE phase | -Berberis repens phase | -creeping holly grape phase |
| | PSME/LIBO h.t. | Pseudotsuga menziesii/Linnaea borealis h.t. | Douglas-fir-twinflower |
| | -ARUV phase | -Arctostaphylos uva-ursi phase | -kinnikinnick phase |

(con.)

Appendix A. (con.)

| ADP code[1] | Abbreviation | Habitat types and phases | |
|---|---|---|---|
| | | Scientific names | Common names |
| IV. MISSOURI RIVER BREAKS[4] | | | |
| | | PINUS PONDEROSA CLIMAX SERIES | |
| | PIPO/JUSC h.t. | Pinus ponderosa/Juniperus scopulorum h.t. | ponderosa pine/Rocky Mountain juniper |
| | | PSEUDOTSUGA MENZIESII CLIMAX SERIES | |
| | PSME/JUSC h.t. | Pseudotsuga menziesii/Juniperus scopulorum h.t. | Douglas-fir/Rocky Mountains juniper |
| | PSME/MUCU h.t. | Pseudotsuga menziesii/Muhlenbergia cuspidata h.t. | Douglas-fir/plins muhly |

[1]Automatic data processing codes for National Forest System use.
[2]Pfister and others 1977.
[3]Roberts 1980.
[4]Roberts and Sibbernsen 1979.

## APPENDIX B. HABITAT TYPE FIRE GROUPS FOR MONTANA FORESTS

**Fire Group 0** – Miscellaneous special habitats:
- Scree;
- Forested rock;
- Meadow;
- Grassy bald;
- Alder glade;
- Aspen grove.

**Fire Group 1** – Dry limber pine habitat types:
- *Pinus flexilis/Agropyron spicatum* (PIFL/AGSP; limber pine/bluebunch wheatgrass)
- *Pinus flexilis/Festuca idahoensis* h.t.-*Festuca idahoensis* phase (PIFL/FEID-FEID; limber pine/Idaho fescue-rough fescue phase)
- *Pinus flexilis/Festuca idahoensis* h.t.-*Festuca scabrella* phase (PIFL/FEID-FESC; limber pine/Idaho fescue-rough fescue phase)
- *Pinus flexilis/Juniperus communis* h.t. (PIFL/JUCO; limber pine/common juniper)

**Fire Group 2** – Warm, dry ponderosa pine habitat types:
- *Pinus ponderosa/Andropogon* spp. h.t. (PIPO/AND; ponderosa pine/bluestem)
- *Pinus ponderosa/Agropyron spicatum* h.t. (PIPO/AGSP; ponderosa pine/bluebunch wheatgrass)
- *Pinus ponderosa/Festuca idahoensis* h.t.-*Festuca idahoensis* phase (PIPO/FEID-FEID; ponderosa pine/Idaho fescue-Idaho fescue phase)
- *Pinus ponderosa/Festuca idahoensis* h.t.-*Festuca scabrella* phase (PIPO/FEID-FESC; ponderosa pine/Idaho fescue-rough fescue phase)
- *Pinus ponderosa/Purshia tridentata* h.t.-*Agropyron spicatum* phase (PIPO/PUTR-AGSP; ponderosa pine/bitterbrush-bluebunch wheatgrass phase)
- *Pinus ponderosa/Purshia tridentata* h.t.-*Festuca idahoensis* phase (PIPO/PUTR-FEID; ponderosa pine/bitterbrush-Idaho fescue phase)
- *Pinus ponderosa/Symphoricarpos albus* h.t.-*Symphoricarpos albus* phase (PIPO/SYAL-SYAL; ponderosa pine/snowberry-snowberry phase) *Pinus ponderosa/Symphoricarpos occidentalis* h.t. (PIPO/SYOC; ponderosa pine/western snowberry)
- *Pinus ponderosa/Arctostaphylos uva-ursi* h.t. (PIPO/ARUV; ponderosa pine/kinnikinnick)
- *Pinus ponderosa/Juniperus horizontalis* h.t. (PIPO/JUHO; ponderosa pine/horizontal juniper)
- *Pinus ponderosa/Juniperus scopulorum* h.t. (PIPO/JUSC; ponderosa pine/Rocky Mountain juniper)

**Fire Group 3** – Warm, moist ponderosa pine habitat types:
- *Pinus ponderosa/Symphoricarpos albus* h.t.-*Berberis repens* phase (PIPO/SYAL-BERE; ponderosa pine/snowberry-creeping Oregon grape phase)
- *Pinus ponderosa/Berberis repens* h.t. (PIPO/BERE; ponderosa pine/creeping holly grape)
- *Pinus ponderosa/Amelanchier alnifolia* h.t. (PIPO/AMAL; ponderosa pine/serviceberry)
- *Pinus ponderosa/Prunus virginiana* h.t.-*Prunus virginiana* phase (PIPO/PRVI-PRVI; ponderosa pine/chokecherry-chokecherry phase)
- *Pinus ponderosa/Prunus virginiana* h.t.-*Shepherdia canadensis* phase (PIPO/PRVI-SHCA; ponderosa pine/chokecherry-buffaloberry phase

**Fire Group 4** – Warm, dry Douglas-fir habitat types:
- *Pseudotsuga menziesii/Agropyron spicatum* h.t. (PSME/AGSP; Douglas-fir/bluebunch wheatgrass)
- *Pseudotsuga menziesii/Festuca scabrella* h.t. (PSME/FESC; Douglas-fir/rough fescue)
- *Pseudotsuga menziesii/Physocarpus malvaceus* h.t.-*Calamagrostis rubescens* phase (PSME/PHMA-CARU; Douglas-fir/ninebark-pinegrass phase)
- *Pseudotsuga menziesii/Symphoricarpos albus* h.t.-*Agropyron spicatum* phase (PSME/SYAL-AGSP; Douglas-fir/snowberry-bluebunch wheatgrass phase)
- *Pseudotsuga menziesii/Symphoricarpos occidentalis* h.t.-*Chrysopsis villosa* phase (PSME/SYOC-CHVI; Douglas-fir/western snowberry-hairy golden aster phase)
- *Pseudotsuga menziesii/Symphoricarpos occidentalis* h.t.-*Shepherdia canadensis* phase (PSME/SYOC-SHCA; Douglas-fir/western snowberry-russet buffaloberry phase)
- *Pseudotsuga menziesii/Calamagrostis rubescens* h.t.-*Agropyron spicatum* phase (PSME/CARU-AGSP; Douglas-fir/pinegrass-bluebunch wheatgrass phase)
- *Pseudotsuga menziesii/Calamagrostis rubescens* h.t.-*Pinus ponderosa* phase (PSME/CARU-PIPO; Douglas-fir/pinegrass-ponderosa pine phase)
- *Pseudotsuga menziesii/Spiraea betulifolia* h.t. (PSME/SPBE; Douglas-fir/white spiraea)
- *Pseudotsuga menziesii/Arctostaphylos uva-ursi* h.t. (PSME/ARUV; Douglas-fir/kinnikinnick)
- *Pseudotsuga menziesii/Berberis repens* h.t.-*Arctostaphylos uva-ursi* phase (PSME/BERE-ARUV; Douglas-fir/creeping holly grape- kinnikinnick phase)
- *Pseudotsuga menziesii/*Berberis repens h.t.-*Berberis repens* phase (PSME/BERE-BERE; Douglas-fir/creeping holly grape-creeping holly grape phase)
- *Pseudotsuga menziesii/Juniperus scopularum* h.t. (PSME/JUSC; Douglas-fir/Rocky Mountain juniper)
- *Pseudotsuga menziesii/Muhlenbergia cuspidata* h.t. (PSME/MUCU; Douglas-fir/plains muhly)

**Fire Group 5** – Cool, dry Douglas-fir habitat types:
- *Pseudotsuga menziesii/Calamgrostis rubescens* h.t.-*Agropyron spicatum* phase (PSME/CARU-AGSP, Douglas-fir/pinegrass-bluebunch wheatgrass phase)
- *Pseudotsuga menziesii/Festuca idahoensis* h.t. (PSME/FEID; Douglas-fir/Idaho fescue)
- *Pseudotsuga menziesii/Carex geyeri* h.t. (PSME/CAGE; Douglas-fir/elk sedge
- *Pseudotsuga menziesii/Arnica cordifolia* h.t. (PSME/ARCO; Douglas-fir/heartleaf arnica)
- *Pseudotsuga menziesii/Symphoricarpos oreophilus* h.t. (PSME/SYOR; Douglas-fir/mountain snowberry)
- *Picea/Senecio streptanthifolius* h.t.-*Pseudotsuga menziesii* phase (PICEA/SEST-PSME; spruce/cleft-leaf groundsel-Douglas-fir phase)

**Fire Group 6** – Moist Douglas-fir habitat types:
- *Pseudotsuga menziesii/Physocarpus malvaceus* h.t.-*Physocarpus malvaceus* phase (PSME/PHMA-PHMA; Douglas-fir/ninebark-ninebark phase)
- *Pseudotsuga menziesii/Viola canadensis* h.t. (PSME/VICA; Douglas-fir/Canadian violet)

*(con.)*

*Pseudotsuga menziesii/Vaccinium globulare* h.t.-*Vaccinium globulare* phase (PSME/VAGL-VAGL; Douglas-fir/blue huckleberry-blue huckleberry phase)
*Pseudotsuga menziesii/Vaccinium globulare* h.t.-*Arctostaphylos uva-ursi* phase (PSME/VAGL-ARUV; Douglas-fir/blue huckleberry- kinnikinnick phase)
*Pseudotsuga menziesii/Vaccinium globulare* h.t.-*Xerophyllum tenax* phase (PSME/VAGL-XETE; Douglas-fir/blue huckleberry-beargrass phase)
*Pseudotsuga menziesii/Linnaea borealis* h.t.-*Symphoricarpos albus* phase (PSME/LIBO-SYAL; Douglas-fir/twinflower-snowberry phase)
*Pseudotsuga menziesii/Linnaea borealis, Arctostaphylos uva-ursi* phase (PSME/LIBO-ARUV; Douglas-fir/twinflower-kinnikinnick phase)
*Pseudotsuga menziesii/Linnaea borealis* h.t.-*Calamagrostis rubescens* phase (PSME/LIBO-CARU; Douglas-fir/twinflower- pinegrass phase)
*Pseudotsuga menziesii/Linnaea borealis* h.t.-*Vaccinium globulare* phase (PSME/LIBO-VAGL; Douglas-fir/twinflower-blue huckleberry phase)
*Pseudotsuga menziesii/Symphoricarpos albus* h.t.-*Calamagrostis rubescens* phase (PSME/SYAL-CARU; Douglas-fir/snowberry-pinegrass phase)
*Pseudotsuga menziesii/Symphoricarpos albus* h.t.-*Symphoricarpos albus* phase (PSME/SYAL-SYAL; Douglas-fir/snowberry-snowberry phase)
*Pseudotsuga menziesii/Amelanchier alnifolia* h.t. (PSME/AMAL; Douglas-fir/serviceberry)
*Pseudotsuga menziesii/Calamagrostis rubescens* h.t.-*Arctostaphylos uva-ursi* phase (PSME/CARU-ARUV; Douglas-fir/pinegrass-kinnikinnick phase)
*Pseudotsuga menziesii/Calamagrostis rubescens* h.t.-*Calamagrostis rubescens* phase (PSME/CARU-CARU; Douglas-fir/pinegrass-pinegrass phase)
*Pseudotsuga menziesii/Vaccinium caespitosum* h.t. (PSME/VACA; Douglas-fir/dwarf huckleberry)
*Pseudotsuga menziesii/Juniperus communis* h.t. (PSME/JUCO; Douglas-fir/common juniper)

**Fire Group 7** – Cool habitat types usually dominated by lodgepole pine:
*Pseudotsuga menziesii/Juniperus communis* h.t. (PSME/JUCO; Douglas-fir/common juniper)
*Pseudotsuga menziesii/Vaccinium caespitosum* h.t. (PSME/VACA; Douglas-fir/dwarf huckleberry)
*Pseudotsuga menziesii/Cornus canadensis* h.t.-*Linnaea borealis* phase (PSME/COCA-LIBO; Douglas-fir/bunchberry dogwood-twinflower phase)
*Pseudotsuga menziesii/Cornus canadensis* h.t.-*Vaccinium myrtillus* phase (PSME/COCA-VAMY; Douglas-fir/bunchberry dogwood-myrtle whortleberry phase)
*Picea/Vaccinium caespitosum* h.t. (PICEA/VACA; spruce/dwarf huckleberry)
*Picea/Linnaea borealis* h.t. (PICEA/LIBO; spruce/twinflower)
*Abies lasiocarpa/Vaccinium caespitosum* h.t. (ABLA/VACA; subalpine fir/dwarf huckleberry)
*Abies lasiocarpa/Calamagrostis canadensis* h.t.-*Vaccinium caespitosum* phase (ABLA/CACA-VACA; subalpine fir/bluejoint-dwarf huckleberry phase)
*Abies lasiocarpa/Linnaea borealis* h.t.-*Vaccinium scoparium* phase (ABLA/LIBO-VASC; subalpine fir/twinflower-grouse whortleberry phase)
*Abies lasiocarpa/Xerophyllum tenax* h.t.-*Vaccinium scoparium* phase (ABLA/XETE-VASC; subalpine fir/beargrass-grouse whortleberry phase)
*Abies lasiocarpa/Vaccinium globulare* h.t. (ABLA/VAGL; subalpine fir/blue huckleberry)
*Abies lasiocarpa/Vaccinium scoparium* h.t.-*Calamagrostis rubescens* phase (ABLA/VASC-CARU; subalpine fir/grouse whortleberry- pinegrass phase)
*Abies lasiocarpa/Vaccinium scoparium* h.t.-*Vaccinium scoparium* phase (ABLA/VASC-VASC; subalpine fir/grouse whortleberry-grouse whortleberry phase)
*Abies lasiocarpa/Carex geyeri* h.t.-*Carex geyeri* phase (ABLA/CAGE-CAGE; subalpine fir/elk sedge-elk sedge phase)
*Pinus contorta/Purshia tridentata* h.t. (PICO/PUTR; lodgepole pine/bitterbrush)
*Pinus contorta/Vaccinium caespitosum* h.t. (PICO/VACA; lodgepole pine/dwarf huckleberry)
*Pinus contorta/Linnaea borealis* h.t. (PICO/LIBO; lodgepole pine/twinflower)
*Pinus contorta/Vaccinium scoparium* h.t. (PICO/VASC; lodgepole pine/grouse whortleberry)
*Pinus contorta/Calamagrostis rubescens* h.t. (PICO/CARU; lodgepole pine/pinegrass)
*Pinus contorta/Juniperus communis* h.t. (PICO/JUCO; lodgepole pine/common juniper)

**Fire Group 8** – Dry, lower subalpine habitat types:
*Picea/Linnaea borealis* h.t. (PICEA/LIBO; spruce/twinflower)
*Picea/Physocarpus malvaceus* h.t. (PICEA/PHMA; spruce/ninebark)
*Picea/Smelacina stellata* h.t. (PICEA/SMST spruce/starry Solomon's seal)
*Abies lasiocarpa/Xerophyllum tenax* h.t.-*Vaccinium globulare* phase (ABLA/XETE-VAGL; subalpine fir/beargrass-blue huckleberry phase)
*Tsuga mertensiana/Xerophyllum tenax* h.t. (TSME/XETE; mountain hemlock/beargrass)
*Abies lasiocarpa/Vaccinium scoparium* h.t.-*Thalictrum occidentale* phase (ABLA/VASC-THOC; subalpine fir/grouse whortleberry-western meadowrue phase)
*Abies lasiocarpa/Calamagrostis rubescens* h.t. (ABLA/CARU; subalpine fir/pinegrass)
*Abies lasiocarpa/Clematis pseudoalpina* h.t. (ABLA/CLPS; subalpine fir/virgin's bower)
*Abies lasiocarpa/Arnica cordifolia* h.t. (ABLA/ARCO; subalpine fir/heartleaf arnica)
*Abies lasiocarpa/Carex geyeri* h.t.-*Pseudotsuga menziesii* phase (ABLA/CAGE-PSME; subalpine fir/elk sedge-Douglas-fir phase)

**Fire Group 9** – Moist, lower subalpine habitat types:
*Picea/Equisetum arvense* h.t. (PICEA/EQAR; spruce/common horsetail)
*Picea/Clintonia uniflora* h.t.-*Vaccinium caespitosum* phase (PICEA/CLUN-VACA; spruce/queencup beadlily-dwarf huckleberry phase)

(con.)

*Picea/Clintonia uniflora* h.t.-*Clintonia uniflora* phase (PICEA/CLUN-CLUN; spruce/queencup beadlily-queencup beadlily phase)
*Picea/Galium triflorum* h.t. (PICEA/GATR; spruce/sweetscented bedstraw)
*Abies lasiocarpa/Oplopanox horridus* h.t. (ABLA/OPHO; subalpine fir/devil's club)
*Abies lasiocarpa/Clintonia uniflora* h.t.-*Clintonia uniflora* phase (ALBA/CLUN-CLUN; subalpine fir/queencup beadlily-queencup beadlily phase)
*Abies lasiocarpa/Clintonia uniflora* h.t.-*Aralia nudicaulis* phase (ABLA/CLUN-ARNU; subalpine fir/queencup beadlily-wild sarsaparilla phase)
*Abies lasiocarpa/Clintonia uniflora* h.t.-*Vaccinium caespitosum* phase (ABLA/CLUN-VACA; subalpine fir/queencup beadlily-dwarf huckleberry phase)
*Abies lasiocarpa/Clintonia uniflora* h.t.-*Xerophyllum tenax* phase (ABLA/CLUN-XETE; subalpine fir/queencup beadlily-beargrass phase)
*Abies lasiocarpa/Clintonia uniflora* h.t.-*Menziesia ferruginea* phase (ABLA/CLUN-MEFE; subalpine fir/queencup beadlily-menziesia phase)
*Abies lasiocarpa/Galium triflorum* h.t. (ABLA/GATR; subalpine fir/sweetscented bedstraw)
*Abies lasiocarpa/Calamagrostis canadensis* h.t.-*Calamagrostis canadensis* phase (ABLA/CACA-CACA; subalpine fir/bluejoint-bluejoint phase)
*Abies lasiocarpa/Calamagrostis canadensis* h.t.-*Galium triflorum* phase (ABLA/CACA-GATR; subalpine fir/bluejoint-sweetscented bedstraw phase)
*Abies lasiocarpa/Linnaea borealis* h.t. (ABLA/LIBO; subalpine fir/twinflower)
*Abies lasiocarpa/Linnaea borealis* h.t.-*Linnaea borealis* phase (ABLA/LIBO-LIBO; subalpine fir/twinflower-twinflower phase)
*Abies lasiocarpa/Linnaea borealis* h.t.-*Xerophyllum tenax* phase (ABLA/LIBO-XETE; subalpine fir/twinflower-beargrass phase)
*Abies lasiocarpa/Menziesia ferruginea* h.t. (ABLA/MEFE; subalpine fir/menzeisia phase)
*Tsuga mertensiana/Menziesia ferruginea* h.t. (TSME/MEFE; mountain hemlock/menzieia)
*Abies lasiocarpa/Alnus sinuata* h.t. (ABLA/ALSI; subalpine fir/Sitka alder)

**Fire Group 10** – Cold, moist upper subalpine and timberline habitat types:
*Picea/Senecio streptanthifolius* h.t.-*Picea* phase (PICEA/SEST-PICEA; spruce/cleft-leaf groundsel-spruce phase)
*Picea/Juniperus communis* h.t. (PICEA/JUCO; spruce/common juniper)
*Abies lasiocarpa/Ribes montigenum* h.t. (ABLA/RIMO; subalpine fir/mountain gooseberry)
*Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium* h.t. (ABLA-PIAL/VASC; subalpine fir-whitebark pine/grouse whortleberry)
*Abies lasiocarpa/Luzula hitchcockii* h.t.-*Vaccinium scoparium* phase (ABLA/LUHI-VASC; subalpine fir/smooth woodrush-grouse whortleberry phase)
*Abies lasiocarpa/Luzula hitchcockii* h.t.-*Menziesia ferruginea* phase (ABLA/LUHI-MEFE; subalpine fir/smooth woodrush-menziesia phase)
*Abies lasiocarpa/Juniperus communis* h.t. (ABLA/JUCO; subalpine fir/common juniper)
*Tsuga mertensiana/Luzula hitchcockii* h.t.-*Vaccinium scorparium* phase (TSME/LUHI-VASC; mountain hemlock/smooth woodrush-grouse whortleberry phase)
*Tsuga mertensiana/Luzula hitchcockii* h.t.-*Menziesia ferruginea* phase (TSME/LUHI-MEFE; mountain hemlock/smooth woodrush-menziesia phase)
*Pinus albicaulis-Abies lasiocarpa* h.t.'s (PIAL-ABLA h.t.'s; whitebark pine-subalpine fir)
*Larix lyallii-Abies lasiocarpa* h.t.'s (LALY-ABLA h.t.'s; alpine larch-subalpine fir)
*Pinus albicaulis* h.t.'s (PIAL h.t.'s; whitebark pine)

**Fire Group 11** – Warm, moist grand fir, western hemlock, and western redcedar habitat types:
*Abies grandis/Xerophyllum tenax* h.t. (ABGR/XETE; grand fir/beargrass)
*Abies grandis/Clintonia uniflora* h.t.-*Clintonia uniflora* phase (ABGR/CLUN-CLUN; grand fir/queencup beadlily-queencup beadlily phase)
*Abies grandis/Clintonia uniflora* h.t.-*Aralia nudicaulis* phase (ABGR/CLUN-ARNU; grand fir/queencup beadlily-wild sarsaparilla phase)
*Abies grandis/Clintonia uniflora* h.t.-*Xerophyllum tenax* phase (ABGR/CLUN-XETE; grand fir/queencup beadlily-beargrass phase)
*Abies grandis/Linnaea borealis* h.t.-*Linnaea borealis* phase (ABRG/LIBO-LIBO; grand fir/twinflower-twinflower phase)
*Abies grandis/Linnaea borealis* h.t.-*Xerophyllum tenax* phase (ABGR/LIBO-XETE; grand fir/twinflower-beargrass phase)
*Thuja plicata/Clintonia uniflora* h.t.-*Clintonia uniflora* phase (THPL/CLUN-CLUN; western redcedar/queencup beadlily-queencup beadlily phase)
*Thuja plicata/Clintonia uniflora* h.t.-*Aralia nudicaulis* phase (THPL/CLUN-ARNU; western redcedar/queencup beadlily-wild sarsaparilla phase)
*Thuja plicata/Clintonia uniflora* h.t.-*Menziesia ferruginea* phase (THPL/CLUN-MEFE; western redcedar/queencup beadlily-menziesia phase)
*Thuja plicata/Oplopanax horridus* h.t. (THPL/OPHO; western redcedar/devil's club)
*Tsuga heterophylla/Clintonia uniflora* h.t.-*Clintonia uniflora* phase (TSHE/CLUN-CLUN; western hemlock/queencup beadlily- queencup beadlily phase)
*Tsuga heterophylla/Clintonia uniflora* h.t.-*Aralia nudicaulis* phase (TSHE/CLUN-ARNU; western hemlock/queencup beadlily-wild sarsaparilla phase)

# APPENDIX C. SCIENTIFIC NAMES OF PLANTS MENTIONED IN TEXT

| Common name | Scientific name |
|---|---|
| Alder | Alnus spp. |
| Alpine larch | Larix lyallii |
| Alpine wintergreen | Gaultherea humifusa |
| Antelope bitterbrush | Balsamorhiza sagittata |
| Arrowleaf groundsel | Senecio triangularis |
| Ballhead sandwort | Arenaria congesta |
| Beargrass | Xerophyllum tenax |
| Big sagebrush | Artemisia tridentata |
| Black cottonwood | Populus trichocarpa |
| Blue huckleberry | Vaccinium globulare |
| Bluebunch wheatgrass | Agropyron spicatum |
| Bluejoint | Calamagrostis canadensis |
| Bluestem | Andropogon spp. |
| Broadleaf arnica | Arnica latifolia |
| Bunchberry dogwood | Cornus canadensis |
| Canadian violet | Viola canadensis |
| Chokecherry | Prunus virginiana |
| Cleft-leaf groundsel | Senecio streptanthifolius |
| Common horsetail | Equisetum arvense |
| Common juniper | Juniperus communis |
| Creeping holly grape | Berberis repens |
| Creeping juniper | Juniperus horizontalis |
| Creeping Oregon grape | Berberis repens |
| Douglas-fir | Pseudotsuga menziesii |
| Dwarf huckleberry | Vaccinium caespitosum |
| Elk sedge | Carex geyeri |
| Elkweed | Frasera speciosa |
| Engelmann spruce | Picea engelmannii |
| Fairy bells | Disporum trachycarpum |
| False Solomon's seal | Smilacina racemosa |
| Grouse whortleberry | Vaccinium scoparium |
| Hairy goldenaster | Chrysopsis villosa |
| Heartleaf arnica | Arnica cordifolia |
| Horizontal juniper | Juniperus horizontalis |
| Idaho fescue | Festuca idahoensis |
| Junegrass | Koeleria cristata |
| Kinnikinnick | Arctostaphylos uva-ursi |
| Limber pine | Pinus flexilis |
| Lodgepole pine | Pinus contorta |
| Mountain arnica | Arnica latifolia |
| Mountain death camas | Zigadenus elegans |
| Mountain gooseberry | Ribes montigenum |
| Mountain lover | Pachistima myrsinites |
| Mountain snowberry | Symporicarpos oreophilus |
| Myrtle whortleberry | Vaccinium myrtillus |
| Ninebark | Physocarpus malvaceus |
| Northern bedstraw | Galium boreale |
| Oceanspray | Holodiscus discolor |
| Paper birch | Betula papyrifera |
| Parry rush | Juncus parryi |
| Pinegrass | Calamagrostis rubescens |

| Common name | Scientific name |
|---|---|
| Plains muhly | Muhlenbergia cuspidata |
| Ponderosa pine | Pinus ponderosa |
| Prickly currant | Ribes lacustre |
| Pussytoes | Antennaria racemosa |
| Quaking aspen | Populus tremuloides |
| Queencup beadlily | Clintonia uniflora |
| Red baneberry | Actaea rubra |
| Red mountain heath | Phyllodoce empetriformis |
| Redoiser dogwood | Cornus stolonifera |
| Richardson's geranium | Geranium richardsonii |
| Rocky Mountain juniper | Juniperus scopulorum |
| Ross sedge | Carex rossii |
| Rough fescue | Festuca scabrella |
| Russet buffaloberry | Shepherdia canadensis |
| Serviceberry | Amelanchier alnifolia |
| Showy aster | Aster conspicuus |
| Shrubby cinquefoil | Potentilla fruticosa |
| Sidebells pyrola | Pyrola secunda |
| Sitka alder | Alnus sinuata |
| Slender hawkweed | Hieracium gracile |
| Smooth woodrush | Luzula hitchcockii |
| Snowberry | Symphoricarpos albus |
| Spike trisetum | Trisetum spicatum |
| Spreading dogbane | Apocynum androsaemilifolium |
| Starry Solomon's seal | Smilacina stellata |
| Strawberry | Fragaria spp. |
| Subalpine fir | Abies lasiocarpa |
| Swamp laurel | Kalmia polifolia |
| Sweet cicely | Osmorhiza chilensis |
| Sweetscented bedstraw | Galium triflorum |
| Thimbleberry | Rubus parviflorus |
| Timber milkvetch | Astragalus miser |
| Twinflower | Linnaea borealis |
| Twisted stalk | Streptopus amplexifolius |
| Utah honeysuckle | Lonicera utahensis |
| Valerian | Valeriana dioica |
| Valerian | Valeriana sitchensis |
| Virgin's bower | Clematis pseudoalpina |
| Wax currant | Ribes cereum |
| Western groundsel | Lithospermum ruderale |
| Western meadowrue | Thalictrum occidentale |
| Western snowberry | Symphoricarpos occidentalis |
| Wheeler bluegrass | Poa nervosa |
| White rhododendron | Rhododendron albiflorum |
| White spiraea | Spiraea betulifolia |
| White spruce | Picea glauca |
| Whitebark pine | Pinus albicaulis |
| Wild sarsaparilla | Aralia nudicaulis |
| Wild strawberry | Fragaria virginiana |
| Yellow mountain heath | Phyllodoce glandulifolia |

Fischer, William C.; Clayton, Bruce D.Fire ecology of Montana forest habitat types east of the Continental Divide. Gen. Tech. Rep. INT-141. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 83 p.

Provides information on fire as an ecological factor for forest habitat types occurring east of the Continental Divide in Montana. Identifies "Fire Groups" of habitat types based on fire's role in forest succession. Describes forest fuels and suggests considerations for fire management.

KEYWORDS: fire ecology, forest ecology, forest fire, fire management, habitat types, forest fuels

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The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-142

April 1983

# Field Procedures for Verification and Adjustment of Fire Behavior Predictions

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## RESEARCH SUMMARY

The problems of verifying fire predictions at the operational level are discussed and four fire prediction situations identified: (1) predicting fire spread several hours before it is expected, using a weather forecast; (2) predicting fire spread just before it occurs, using measured weather data; (3) predicting fire spread after the fact, with weather data measured during the fire; (4) predicting fire behavior after the fact, with all of the fire model inputs measured rather than inferred. Opportunities and problems associated with several types of fire, including wildfires, prescribed fires, both planned and unplanned, as well as fires dedicated to verification, are discussed. Procedures for collecting and analyzing data are detailed for accessible fires and inaccessible fires. Analyses for choosing the appropriate fuel model, for evaluating prediction capability, and for improving predictions by the use of simple linear regression techniques are explained and illustrated with examples from the field.

## CONTENTS



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# Field Procedures for Verification and Adjustment of Fire Behavior Predictions

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**George C. Rinehart**

## INTRODUCTION

Methods for predicting fire spread and related intensity values are becoming available in many forms. Albini's nomographs or nomograms introduced in 1976 were followed by the TI-59 calculator (Burgan 1979). Rothermel (1983) has shown how to integrate these tools into a complete predictive system, including methods for obtaining the fuel and environmental conditions needed as inputs, and how to interpret the outputs into useful fire descriptors. These methods were originally developed for the S-590 Fire Behavior Officers' Course.[1] Similar procedures based on the same research are being incorporated into a revised S-390 Fire Behavior Course.[2] The nomenclature and methods used in this paper assume the reader is familiar with the fire prediction procedures and associated fuel and weather procedures described in the above references.

The capability to predict fire spread has created a need to determine how well the methods and procedures work in local fuel and fire situations. The intent of these verification procedures is not to validate the fire spread model (Rothermel 1972), which is only one part of the overall prediction system, but to verify the complete system, including the fire spread model and all associated models and interpretation aids. Testing the fire spread model requires more elaborate procedures, including careful measurement of fuels and continuous monitoring of environmental factors. Such tests have been made by a few well planned research experiments. These include tests by Lawson (1972) in needle litter; by Brown (1972) in fuel arrays assembled from logging slash; by Sneeuwjagt and Frandsen (1976) in grass; by Bevins (1976) in logging slash; and by Hough and Albini (1978) in southern rough. A summary of these tests (except Lawson's) is given by Andrews (1980). A composite illustration of the results is shown in figure 1. These tests demonstrate that the fire behavior model can predict rate of spread with creditable accuracy and do it in fuels as diverse as grass and logging slash. The question remains: How well will the complete prediction system work in your fuels and under your conditions? This manual will answer that question and also tell how to improve your predictions.

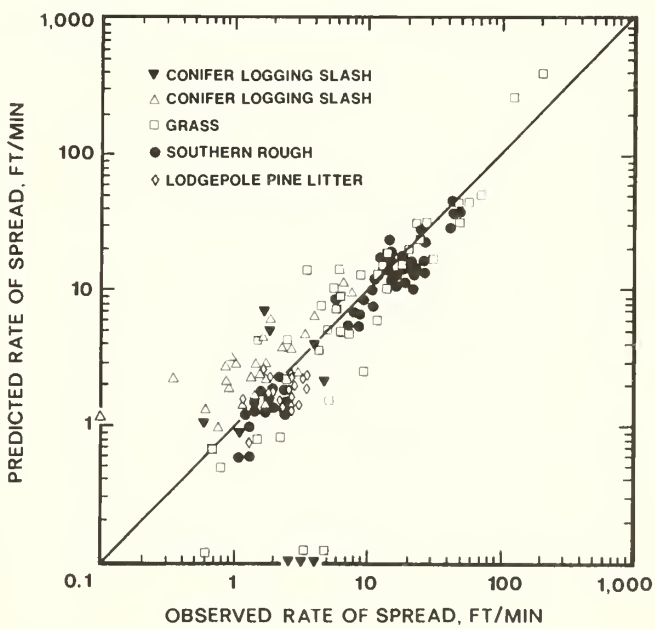


***Figure 1.—This logarithmic chart dampens the amplitude of the variation as rate of spread increases, but shows the trend and allows a wide diversity of spread rate to be included on one graph. Data obtained from these sources: conifer logging slash (solid triangles), Bevins (1976); conifer logging slash (open triangles), Brown (1972); grass, Sneeuwjagt and Frandsen (1966); southern rough, Hough and Albini (1978); lodgepole pine litter, Lawson (1972).***

[1]Two-week course taught at the National Advanced Resource Technology Center at Marana Air Park, Ariz.

[2]National Wildfire Coordinating Group's S-390 Fire Behavior Course. Produced by Boise Interagency Fire Center; Joe Duft and Jerry Williams, co-chairmen of course development.

The verification concept is simple: obtain data necessary to predict fire behavior and corresponding data on actual fire behavior, then compare the prediction with the actual fire. In practice this is often difficult to do, especially on wildfires. The best example of such data is described by Norum (1982) who analyzed spread rate and flame length data from thousands of acres of fires in Alaska. The results of his analysis of rate of spread are shown in figure 2. Many users do not have access to the large amount of data available to Norum; however, there are many opportunities for collecting data and this paper explains the philosophy of testing, the methods of obtaining data, methods for analysis, and finally, methods for interpreting and calibrating outputs to better match the behavior of fires in unique local fuels.

The verification and calibration methods that are presented do not require sampling of fuel quantity or fuel moisture or impose a requirement for expensive equipment not ordinarily available to operating units.

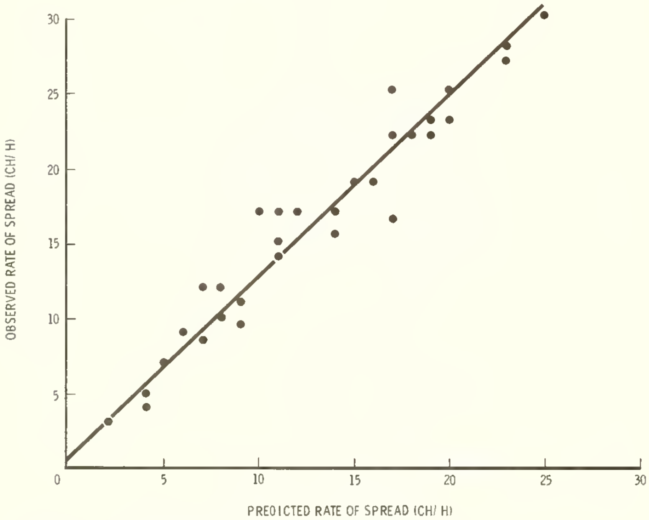


***Figure 2.—Verification of the methods for predicting fire behavior applied to Alaska black spruce forests (Norum 1982).***

## DISCUSSION

The ultimate goal is to improve fire behavior predictions. This will be accomplished by:

—Verifying accuracy of predictions.

—Developing adjustment factors for unique local fuels.

—Correct utilization of the prediction system.

Control efforts on wildfires often become so hectic that it is difficult to verify predictions. Therefore, other fire situations may have to be utilized to obtain verification data.

Before procedures are discussed, it is worth considering both the types of test situations that may be encountered and the types of fires that may be utilized for obtaining verification data. There are many combinations of these and it is not possible to specify a particular data collection procedure for all of them. In fact, the overriding consideration that requires significantly different procedures is access to the fire.

The data collection and analysis procedures that follow later will outline methods that are applicable for either accessible fires or inaccessible fires. The user may adapt the procedures as appropriate for the particular test situation and type of fire available for his/her use.

## TEST SITUATIONS

The test situations depend primarily upon how the inputs, particularly weather, will be obtained, and the sequence for obtaining data.

Four test situations are likely to be encountered:

1. Fire predictions with forecasted weather.
2. Fire predictions with weather observed prior to a fire.
3. Fire predictions with weather observed during a fire.
4. Fire predictions with all variables measured.

**Situation 1.**—Forecasted weather. This test is conducted under the same conditions that a fire behavior officer (FBO) would encounter when fire spread is predicted, utilizing a weather forecast well ahead of the time period of the expected fire growth. The FBO would normally have had a chance to see the fuels and topography of the area where the fire will be. If the forecasted weather does not materialize, verification data will not qualify for situation 1, but may be used to qualify for situation 2.

**Situation 2.**—Observed weather prior to a fire. In this situation a fire spread prediction is made with observed weather taken on site just prior to the fire. This situation is often encountered on prescribed fires. It does not have the uncertainty of a weather forecast, but the input data are available prior to the fire.

**Situation 3.**—Observed weather during a fire. For this situation fire spread is calculated with weather, particularly wind, measured periodically during the fire. This does not verify the ability to predict fire behavior prior to the event, but does allow the system accuracy to be verified when weather inputs are as well defined as the situation will allow. This situation will be used to develop calibration factors for different fuel types.

**Situation 4.**—All input variables measured. This test situation requires careful measurement of fuels, fuel moisture, windspeed, and slope. This would require extensive instrumentation and subsampling, and is in the nature of a research study such as performed by Brown (1972), Lawson (1972), Sneeuwjagt (1974), or Bevins (1976). Such studies are outside the scope of this paper.

The four situations present a paradox about the nature of prediction and verification.

Test situation 1, where all the data are assembled many hours before the expected time of fire spread, will likely have the poorest correlation between predicted and observed behavior, but because it is closest to the real situation, the results are unique and valuable.

Test situation 3 will provide the best test of the prediction ability of the system because conditions are measured and updated periodically during a fire. This provides the best data, but does not simulate real world predictive procedures as is done in situation 1.

From this discussion we can draw three conclusions:

1. All testing is not the same.
2. Data taken from the three situations should be analyzed and evaluated separately as was done by Andrews (1980).
3. Users should choose the type of test situation that meets their objectives.

## Types of Fires

It is usually difficult to obtain good data on the behavior and location of fire perimeters on wildfires, especially during the early stages. Therefore it is important that other types of fires be used, including prescribed fires, as well as experimental fires designed for verification. A discussion of the types of fires that may be used to obtain data for the three test situations, along with opportunities and problems that are likely to be encountered, are given below.

#### UNPLANNED, PRESCRIBED FIRES

Unplanned, prescribed fires come closest to matching a wildfire situation. These fires result from unplanned or natural ignition (lightning) in an area that has been designated for fire treatment in a management plan. Suppression activities on unplanned prescribed fires are usually confined to protecting boundaries or structures. Additional ignitions are usually not made. Because these fires can exist through several burning periods, they offer excellent opportunities for verification in the first situation, i.e., using a weather forecast to predict fire behavior before the event. The second and third situations for verifying and testing with measured data may be more difficult because of inaccessibility or safety considerations, but should not be ruled out. This should be done with a team monitoring the fire without other duties and responsibilities.

#### PLANNED, PRESCRIBED FIRES

Planned, prescribed fires are conducted for one or more management purposes, such as fuel reduction, wildlife habitat improvement, seedbed preparation, etc. They are almost always conducted within one burning period and therefore do not allow the opportunity for repeating predictions with forecasted weather. Specified weather conditions are normally selected to produce behavior less severe than encountered on escaped wildfires. Results of tests, therefore, will usually not cover the range of fire severity experienced on wildfires.

A more serious problem is the method of ignition. Ignition patterns or sequences are often used to **control** fire behavior. There are presently no modeling methods that will account for the resulting fire interactions. For instance, center ignition to build a strong convection column with strong indrafts followed by perimeter ignitions will result in the line fires on the perimeter being pulled toward the center and consequently do not meet the criteria of a free-burning line fire. These cannot be used for verification. Some prescribed fires, however, are ignited by strip head firing. These fires are not ideal free-burning line fires, and the data may not always be useful, but can be considered if the width between strips is wide and the fire can reach a steady state between strips. Many fire officers use the model as an indication of potential severity of prescribed fires, but this manual deals with verification, not methods of characterizing prescribed fire.

Backing fires may also be compared with a prediction that utilizes zero windspeed and zero slope as inputs. These fires move very slowly, but help to indicate the limits of combustion.

#### WILDFIRES

Wildfires, even those being suppressed, can provide opportunities for taking data on rate of spread if the fireline is not completely secure and if retardant or water is not being applied to open sections of line. There may also be spot fires beyond the lines that can be observed as they start and grow or the fire may make an unsuppressed run. Access may be limited on wildfires, and smoke and flame or uneven terrain can prevent good observation of the fire's actual location. All these problems are accentuated during the first few hours on a fire until things begin to settle down and the FBO can find vantage points where data can be taken. Aerial infrared imagery provides excellent perimeter data if it is available before the next burning period.

#### VERIFICATION TEST FIRES

Verification fires are designed specifically for the purpose of collecting data to verify fire spread predictions, and to determine calibration constants for matching fuel models to local fuels. These fires would normally be conducted under test situation 3 where weather is measured during the fire. Because both the time and place of the fire are selected, the test is under better control than in other fires and there is a better chance for obtaining good data.

# PROCEDURES

Because of the concern for safety and the severe restrictions that accessibility of the fire can cause, the procedures are divided and explained for either accessible fires or fires with restricted accessibility.

## Accessible Fires

The procedures for accessible fires outlined below assume that workers can safely reach and gather data near the fire. The procedures may be used with any of the fire types discussed earlier. These procedures stress the importance of obtaining data when conditions are as uniform as possible to eliminate that uncertainty from obscuring the results. This would normally be done with a series of tests in one kind of fuel. The location of the expected burn area should be well defined and the time of observation will be short compared to the usual procedure of wildfire monitoring. Procedures for verifying predictions over longer periods, say 2 to 4 hours in an afternoon as a fire spreads unconfined, are discussed in the section on inaccessible fires.

Two types of data are required: the data needed to make fire behavior predictions, and data that records what the fire did. Because conditions change as time goes on and as the fire grows, it is necessary to coordinate the data collection so the results can be related. This is accomplished by organizing data collection by time periods. Those things that remain relatively constant, such as slope and fuel type, can be predetermined and those things that change rapidly, such as weather, fire position, and flame length, are recorded by time period. The perimeter of the fire must be known at the beginning and end of each period of time. The descriptors of fuels, weather, and topography during each period are used to predict rate of spread and flame length.During each period the two parameters most likely to change (wind and fire location) should be given the most attention.

A data sheet designed for recording observations of both the fire environment and the fire behavior is shown in figure 3. Each column is for one time period. Data from other sources such as photographs, recorded verbal comments, or measurements of fire spread distance may be entered later. The data sheet should be used in conjunction with a high resolution map on which the best estimate of the location of the fire perimeter

Figure 3
FIRE OBSERVATION DATA SHEET

Observer's Name ______________________ Date ______________

Fire Identification ______________________________________

Section of line identification ___________________________

__________________________________________________________

| INPUTS | | | | | | | |
|---|---|---|---|---|---|---|---|
| Start time | | | | | | | |
| Projection point | | | | | | | |
| Slope | | | | | | | |
| Aspect | | | | | | | |
| Elevation | | | | | | | |
| Fuel model | | | | | | | |
| Shade percent | | | | | | | |
| Dry bulb temp. | | | | | | | |
| Wet bulb temp. | | | | | | | |
| Relative humidity | | | | | | | |
| Live fuel moisture | | | | | | | |
| 20' windspeed | | | | | | | |
| Handheld anemometer windspeed | | | | | | | |
| Wind direction | | | | | | | |
| Fire, wind, slope direction | | | | | | | |
| FIRE OBSERVATIONS | | | | | | | |
| Average flame length | | | | | | | |
| Maximum flame length | | | | | | | |
| Overstory torching | | | | | | | |
| Overstory crowning | | | | | | | |
| Firewhirls | | | | | | | |
| Spotting occurrence | | | | | | | |
| Spotting distance | | | | | | | |
| Spread distance | | | | | | | |
| End time | | | | | | | |

*Figure 3.—Fire observation data sheet.*

can be sketched. Use a portable tape recorder for making quick verbal descriptions of fire behavior and reasons for starting and stopping test periods. The recorder is superior to written notes because it is much faster, and you can talk while watching the fire.

## FIRE OBSERVATION DATA SHEET

### *Heading*

Enter the observer's name and the date on which the data are taken.

Identify the fire.

Identify the section of the fire on which the data are taken.

Space is available for other identifying information.

### *Start Time*

Enter the time of day (24-hour time) that an observation is to begin. This is not time of ignition, but the time that a line of fire has developed that is independent of its ignition source and has reached a relatively steady state. Fuel ahead of the fire should be of the same type for a sufficient distance to obtain a reasonable spread measurement. If the wind changes significantly in speed or direction, the time period may have to be terminated (see End Time).

### *Projection Point*

The designation "projection point" is used to identify the position from which the growth of the fire will be projected and monitored. Identify the projection point on a map.

### *Inputs*

**Slope.**—Measure the slope. This can be done with a hand-held instrument. Learn to disregard undulations that are small with respect to the size of the fire or that the fire may cross in a time short compared to the observed run time. It may be more convenient to measure slope after the fire.

**Aspect.**—Record the aspect as one of the four cardinal directions or a combination of two of them.

**Elevation.**—Record the elevation in feet.

**Fuel model.**—Observe the fuel stratum that is carrying the fire. Photograph the fuel, both with and without fire in the scene. Dictate a description of the fuel into the recorder, noting the type of fuel, e.g., grass, shrubs, litter, or slash. Describe both the living and dead material and the relative abundance of each. Describe the stage of growth or the curing of the live fuel and its coloration. If the fuels are nonuniform, one fuel model may not be satisfactory to represent the area. Another option is to use the two-fuel-model concept (see appendix). Enter two fuel models that describe the area, the first that describes the dominant fuel cover and the second that describes significant concentrations within the first. Below the fuel model number enter the estimated percent cover of each fuel.

**Shade factor.**—Ignition component and 1-hour timelag fuel moisture calculations are affected by the shading of fuels at the fire site. Shading can result from either cloud cover or canopy cover. Estimate the percent shading.

**Dry bulb temperature.**—Enter dry bulb air temperature (be sure thermometer is shaded and ventilated).

**Wet bulb temperature.**—Enter wet bulb temperature. Follow prescribed procedures for accurate measurements.

**Relative humidity.**—Convert dry bulb temperature and wet bulb temperature to RH, using a chart for the appropriate elevation (not needed until ready to estimate dead fuel moisture and fire behavior).

**Live fuel moisture.**—Estimate the live fuel moisture from the guide provided by Rothermel (1983). If live fuel moisture is measured include only the foliage and fine stems, and do not mix live and dead samples.

**20-ft windspeed.**—For exposed fuels that are not beneath a timber canopy, such as grass, shrubs, or logging slash, a continuous measurement of windspeed at the standard 20-ft height can be very helpful. Set the anemometer at a location that will be as representative as possible of the wind that will be blowing over the fire. If possible it should be upwind of the fire on the order of 15 to 20 times the expected flame length from the fire. For example, if the flame lengths are expected to be 4 ft, the anemometer should be at least 60 to 80 ft away. Closer locations will be influenced by indrafts to the fire. Since the system is designed to be a predictive system, it must work with forecasted winds that would be present in the absence of fire. The fire model is designed to account for indrafts to unrestricted line fires in surface fuels.

**Handheld anemometer windspeed.**—Although 20 ft above the vegetation cover is the standard height for taking windspeed observation (Fischer and Hardy 1976), it must be interpreted to determine midflame windspeed needed by the fire model (Rothermel 1983). A good representation of the midflame windspeed can be measured with an anemometer near eye level. A high quality 3-cup handheld anemometer with low starting inertia is recommended. If one is not available, the pith-ball type of wind meter in the belt weather kit can be used.

A two-person team consisting of an observer and a data recorder may be needed for a short time when fire is moving rapidly. Use two clean pith-ball wind meters, one plugged so that it always reads the high scale, and the other open for reading the low scale. Clamp the anemometers together side by side, place them on a rod that can be rotated, and stick it in the ground. Slide the anemometers to the approximate midflame height. Note the height of the anemometers. Rotate the anemometers directly into the wind and call off the position of the ball of the low or high observation; read the low velocity whenever it is on scale. The observations should be repeated at a uniform rate. The recorder should record all the observations made within each time interval. For short fast runs, readings may be needed as often as every 15 seconds; for slow moving, long duration fires, the interval can be much longer. It is important, however, to take the wind data that coincide with a measurement of a fire run; that is, at the same time and in the same body of air.

An alternative to this procedure is to use an averaging anemometer. This instrument records the total travel distance of the air that passes past it from the time it is turned on. This is easily converted into average windspeed by dividing this total distance by the length of time of the observation.

**Wind direction.**—Record the direction the wind is coming from. If it is light and variable, note that fact. Record the direction as one of the four cardinal directions or a combination of two.

A tassel of colored yarn attached to the rod described above will indicate wind direction; the observer should keep the wind meters facing into the wind. If it is not possible to locate a measuring point upwind of the fire in a position that is representative of the same slope on which the fire is burning, then it can be located to the side; but care should be taken that the wind being measured has not traveled over a burning area before it reaches the measuring point.

**Relative directions, fire, wind, and slope.**—Record the direction the head of the fire is spreading with respect to the wind direction and the maximum slope. Examples of four conditions are illustrated in figure 4. It is also possible for the wind to be blowing cross-slope, with the fire spreading fastest in the uphill or downhill direction. A code for recording the directions is given in table 1. Explanation of how to calculate fire spread for cross-slope fires is given by Rothermel (1983). Although the fire model was designed to predict behavior at the head of the fire, it can be adapted to work with backing fires and on the flanks. On a large fire these may be the only accessible places and a record of what the fire spread, wind, and slope directions are at each projection point is essential.

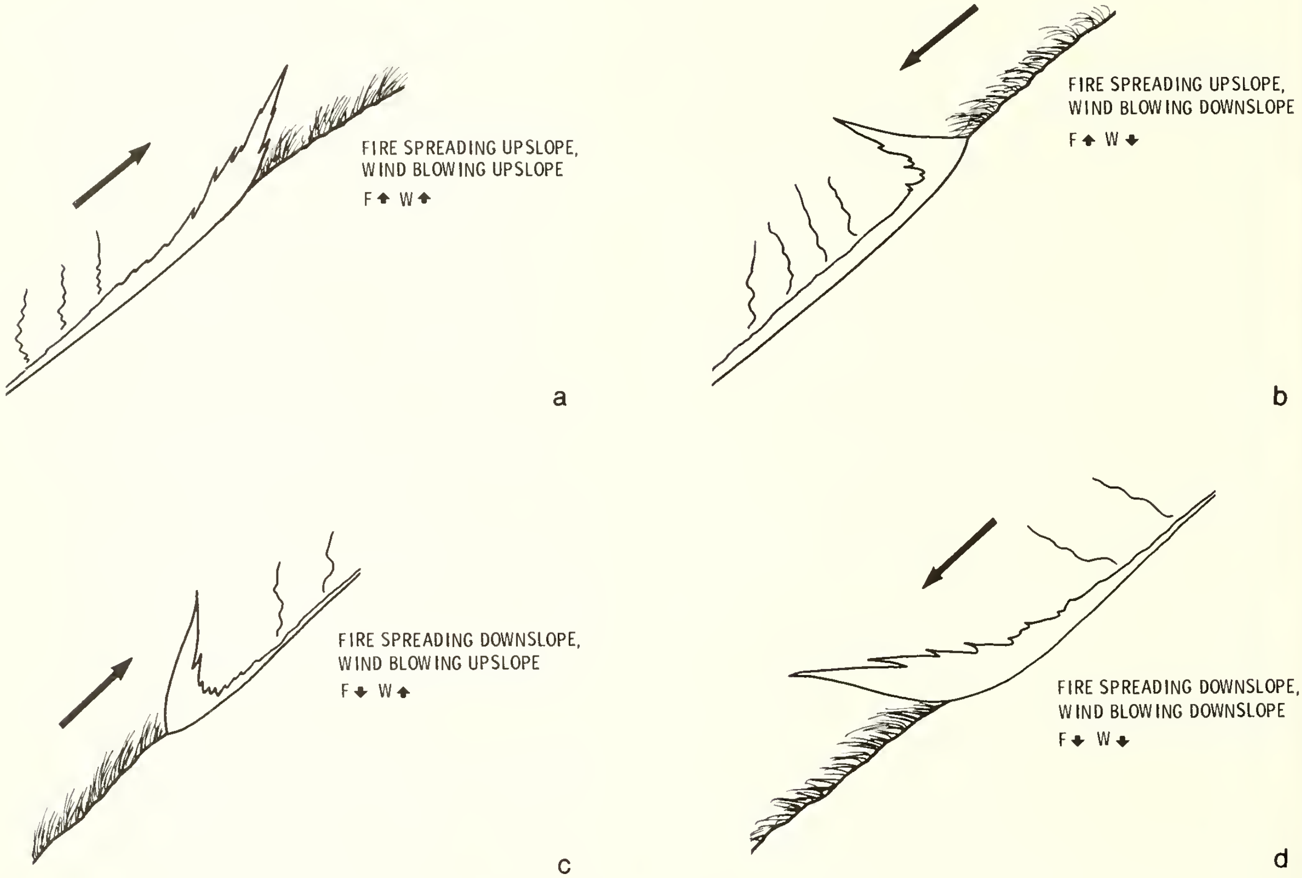


*Figure 4.—Flame shapes on slopes as affected by direction of fire spread and direction of wind.*

**Table 1.**—Symbols for indicating fire spread direction with respect to wind and slope

| Direction of fire spread | Wind direction: Upslope, within ± 30° of maximum | Cross-slope: Upward | Cross-slope: Downward | Downslope, within ± 30° of fall line |
|---|---|---|---|---|
| Upslope side of fire | F↑ W↑<br>Wind and fire going upslope as shown in fig. 4-a | F↑ W↗<br>Upslope side of fire; wind crossing upslope | F↑ W↘<br>Upslope side of fire; wind crossing downslope | F↑ W↓<br>Fire spreading upslope; wind blowing downslope; as shown in fig. 4-b |
| Downslope side | F↓ W↑<br>Fire backing downslope; wind blowing upslope as shown in fig. 4-c | F↓ W↗<br>Fire backing downslope; wind crossing upslope | F↓ W↘<br>Fire spreading downslope; wind crossing downslope | F↓ W↓<br>Fire spreading downslope; wind blowing downslope as shown in fig. 4-d |

*Fire Observations*

**Average flame length.**—Estimate the average flame length along the fireline. Flame length (fig. 5) is the distance between the tip of the flame and the ground (or surface of the remaining fuel) midway in the zone of active flaming. Do not confuse flame height with flame length. It is extremely helpful to have an object of known length to provide a reference scale. Stakes set in the burn area with 1-foot sections painted alternate colors, or with metal flags attached at known spacing (the spacing depends on the expected scale of the flames) are very helpful. Small trees or a person standing near the fire may also be used for scaling. Measure the tree height before or after the fire.

It is difficult to measure flame length. The flame tip is a very unsteady reference; your eye must average the length over a time period that is representative of the fire behavior. Flame length can be estimated from photos of narrow fuel beds, but photographs of large fires taken from the rear are of little use. Infrared photographs give good quality flame images even through smoke (Britton and others 1977). Photographs alone may not provide the data needed. Supplement photos with visual estimates.

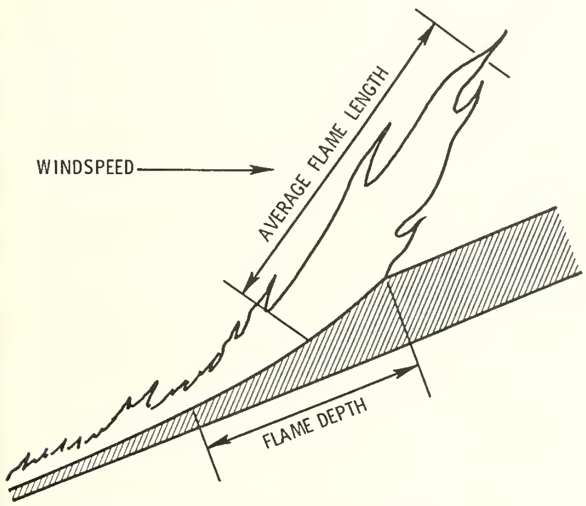


*Figure 5.—Flame dimensions for a wind-driven fire on a slope.*

**Maximum flame length.**—Record the maximum flame length observed along the fireline during the time period.

**Overstory torching.**—Note if torching of overstory trees is occurring.

**Overstory crowning.**—Note if sustained crowning of the overstory is occurring.

**Fire whirls.**—Note the presence of firewhirls. Record the conditions under which they develop, such as the direction of the ambient wind, or wind above the fire with respect to slope.

**Spotting.**—Note if short range spotting is occurring. Note if firebrands landing in front of the fire are starting new fires before the fire front burns over them or if small spot fires are being overrun by the main fire front before significant new fires are started.

If firebrands are being lofted by torching trees or from burning piles, an estimate of the maximum spotting distance can be made using a model developed by Albini (1981). Chase (1981) provides a complete description for predicting the maximum expected spotting distance with Albini's model, using a program developed for the TI-59 calculator. A worksheet is provided and the program can be obtained on a magnetic strip from the Northern Forest Fire Laboratory. We are interested in accurate descriptions of firebrand behavior and spotting distance, and would appreciate receiving this information along with a complete description of the situation as called for by the worksheet in Chase's publication.[3]

**Spread distance.**—Methods of measuring spread distance depend on the size and rate of spread of the fire, and on the equipment available. It is not necessary to map the entire fire perimeter. Figure 6 indicates the data needed. The following suggested methods have been tried. Choose the one that suits your fire situation.

[3]Send data to: Fire Behavior Project, Northern Forest Fire Laboratory, P.O. Drawer G, Missoula, MT 59806.

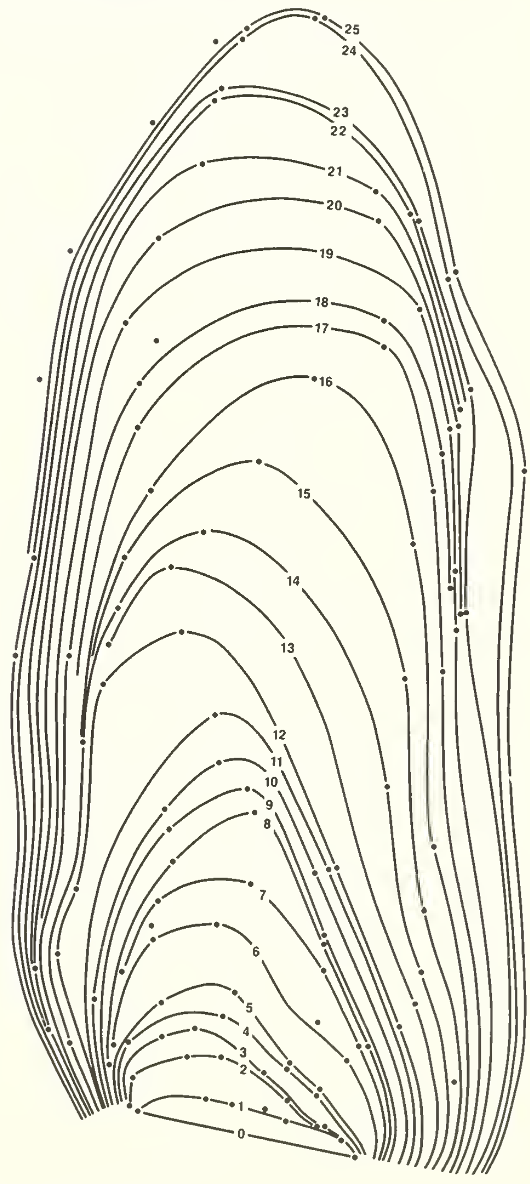


*Figure 6.—Fire growth map showing fire position every minute. Data taken and compiled by Phil Cheney in Australia, 1976. Fire burned in grass, primarily sorghum. Original scale was 1 cm = 20 m. Rate of spread for any interval is the distance traveled divided by the time of the interval.*

1. On low intensity, slow-spreading fires that are safe to move around, numbered metal tags can be dropped or thrown to mark the fire edge. Recent experience by Phil Range and Paul Veisze of the BLM Nevada Office has shown that short pieces of aluminum tubing work well because they are easily found after the fire. The time each marker is thrown is recorded. After the fire has burned out, the distance between successive tags is measured and recorded.

2. If the fire is too severe to move around, observe the fire front and draw contour lines on a high resolution map noting the time that each line is drawn. A handheld rangefinder may be useful to determine distances to landmarks or the fire front.

3. Record fire front locations by photography. Either aerial photos or surface views or both may be used. The time of each photograph must be known without exception. Fire location can then be mapped by noting the relationship between the fire front and visible landmarks. If visible landmarks are lacking, posts or similar targets may be placed in advance of the fire. Black and white infrared film (Kodak high-speed infrared or equivalent) will produce best results because it does not record the smoke image (Britton and others 1977).

4. A handheld rangefinder is particularly useful because of its portability. It does not require preplacement of poles at known distances ahead of the fire. Some form of marker is needed to focus on, but any tree, bush, or rock will do. Identify a marker distance at the beginning of the time period and one at the end. If you are behind the fire and thus observing it in the direction of spread, the distance and time of spread between the points is readily obtained. Triangulation may also be used with staff compass and rangefinder.

5. In some test situations, fireworks such as whistling rockets can be placed at known intervals in the direction of fire spread. Record the time of discharge as the fire passes. To insure that none are missed by the fire, a long fuse should be attached.

**End time.**—Record the time at which you wish to terminate the burning period for the data recorded in this column. As stated, this should be based on a significant change of conditions such as when the fire burns into a new fuel type, or the weather conditions alter with a change in wind direction, windspeed, or fuel moisture. Start a new time if the fire burns onto a different slope, or if the fire stops spreading. The next period does not need to start at the same time the preceding one stops. It is often necessary to reorganize observers and equipment.

## ANALYSIS

The choice of analysis procedure depends upon what you wish to learn from the data as well as completeness of the data. Examples and explanations of data analyses from a variety of fire studies will be given in this section and in the section on inaccessible fires. The analysis outlined below assumes that data were collected as specified in the preceding instructions. Several results can be obtained from the data.

—A determination of the best fuel model to represent fire in a particular fuel.

—An overall evaluation of how well the actual fire behavior matched that predicted.

—Development of a calibration or adjustment factor for the best fuel model and the fuels that were burned.

—Determination of a better moisture of extinction.

### Organize Data

Organize the data from verbal transcripts, photographs, maps, and supplemental rate of spread data sheets by the same time periods used on the fire observation data sheets. Transcribe data from these sources onto the fire observation data sheet.

Study the photos and fuel descriptions and pick the most appropriate fuel model and one or two supplemental fuel models that may be appropriate.

Some data are redundant, and you will have to decide what to use. If you had a well located 20-ft anemometer, convert that data to the midflame height with the wind reduction tables for the appropriate sheltering condition. Otherwise, use the handheld anemometer readings as the midflame windspeed.

If the winds were erratic in direction or speed, or the fire was obviously changing behavior during a time period due to transition of fuels, then the data from that time period may not be useful for developing calibration factors. Analysis of the ability to predict fire growth under any circumstances is given in the section on inaccessible fires.

If the fire was torching, spotting, or crowning, the fire model does not predict the behavior of these events, but the flame length data should indicate the onset of these events as explained in the fire behavior interpretation chart (fig. 7).

### Calculating Fire Behavior

When the initial screening of data is complete, transfer the data needed for predicting fire behavior to a fire behavior worksheet (fig. 8). Calculate fire behavior for each time period and for each fuel model selected according to the methods given by Rothermel (1983).

The calculated and observed values should be in the same units of measure. The nomograms and TI-59 fire CROM give spread rate in chains per hour and flame length in feet. It is often convenient to measure spread rates in feet per minute. To convert chains per hour to feet per minute, multiply chains per hour by 1.1. For example, 75 chains per hour equal 82.5 feet per minute.

FIRE SUPPRESSION INTERPRETATIONS
Interpretations drawn from Roussopoulos and Johnson (1975)

CAUTION: These are not guides to personal safety. Fires can be dangerous at any level of intensity. Wilson (1977) has shown that most fatalities occur in light fuels on small fires or isolated sectors of large fires.

| Flame length (feet) | Fireline intensity (Btu/ft/s) | Interpretations |
|---|---|---|
| < 4 | < 100 | - Fires can generally be attacked at the head or flanks by persons using hand tools.<br>- Handline should hold the fire. |
| 4-8 | 100-500 | - Fires are too intense for direct attack on the head by persons using hand tools.<br>- Handline cannot be relied on to hold fire.<br>- Equipment such as dozers, pumpers, and retardant aircraft can be effective. |
| 8-11 | 500-1000 | - Fires may present serious control problems--torching out, crowning, and spotting.<br>- Control efforts at the fire head will probably be ineffective. |
| > 11 | > 1000 | - Crowning, spotting, and major fire runs are probable.<br>- Control efforts at head of fire are ineffective. |

*Figure 7.—Fire suppression interpretations of flame length and fireline intensity.*

FIRE BEHAVIOR WORKSHEET

Sheet _____ of _____

NAME OF FIRE ____________________ FIRE BEHAVIOR OFFICER _______________

DATE ____________________ TIME _______________

PROJ. PERIOD DATE ____________________ PROJ. TIME FROM ________ to ________

| | INPUT DATA | | | | | | | TI-59 Reg. No. |
|---|---|---|---|---|---|---|---|---|
| 1 | Projection point | | | | | | | |
| 2 | Fuel model proportion, % | | | | | | | |
| 3 | Fuel model | | | | | | | |
| 4 | Shade value 0-10%=0;10-50%=1 50-90%=2;90-100%=3) | | SHADE | | | | | 60 |
| 5 | Dry bulb temperature, °F | | DB | | | | | 61 |
| 6 | Relative humidity, % | | RH | | | | | 62 |
| 7 | 1 H TL FM, % | | 1H | | | | | 28 |
| 8 | 10 H TL FM, % | | 10H | | | | | 63 |
| 9 | 100 H TL FM, % | | 100H | | | | | 30 |
| 10 | Live fuel moisture, % | | LIVE | | | | | 33 |
| 11 | 20-foot windspeed, mi/h | | | ( ) | ( ) | ( ) | ( ) | |
| 12 | Wind adjustment factor | | | ( ) | ( ) | ( ) | ( ) | |
| 13 | Midflame windspeed, mi/h | | M WS | | | | | 79 |
| 14 | Maximum slope, % | | PCT S | | | | | 80 |
| 15 | Projection time, h | | PT | | | | | 81 |
| 16 | Map scale, in/mi | | MS | | | | | 82 |
| 17 | Map conversion factor, in/ch | | | | | | | |
| 18 | Effective windspeed, mi/h | | | | | | | |
| | OUTPUT DATA | | | | | | | |
| 19 | Rate of spread, ch/h | [ A ] | ROS | | | | | 88 |
| 20 | Heat per unit area, Btu/ft$^2$ | [R/S] | H/A | | | | | 90 |
| 21 | Fireline intensity, Btu/ft/s | [ B ] | INT | | | | | 53 |
| 22 | Flame length, ft | [R/S] | FL | | | | | 54 |
| 23 | Spread distance, ch | [ C ] | SD | | | | | 42 |
| 24 | Map distance, in | [R/S] | MD | | | | | 43 |
| 25 | Perimeter, ch | [ D ] | PER | | | | | 40 |
| 26 | Area, acres | [R/S] | AREA | | | | | 89 |
| 27 | Ignition component, % | [ E ] | IC | | | | | 44 |
| 28 | Reaction intensity, Btu/ft$^2$/min | [R/S] | IR | | | | | 52 |

*Figure 8.—Fire behavior worksheet.*

page 1

## FINE DEAD FUEL MOISTURE CALCULATIONS

| | | | | |
|---|---|---|---|---|
| a. Projection point | | | | |
| b. Day or night (D/N) | D/N | D/N | D/N | D/N |
| **DAY TIME CALCULATIONS** | | | | |
| c. Dry bulb temperature, °F | | | | |
| d. Relative humidity, % | | | | |
| e. Reference fuel moisture, % (from table A) | | | | |
| f. Month | | | | |
| g. Exposed or shaded (E/S) | E/S | E/S | E/S | E/S |
| h. Time | | | | |
| i. Elevation change<br>B = 1000'-2000' below site<br>L = ±1000' of site location<br>A = 1000'-2000' above site | B/L/A | B/L/A | B/L/A | B/L/A |
| j. Aspect | | | | |
| k. Slope | | | | |
| l. Fuel moisture correction, % (from table B, C, or D) | | | | |
| m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side) | | | | |
| **NIGHT TIME CALCULATIONS** | | | | |
| n. Dry bulb temperature, °F | | | | |
| o. Relative humidity, % | | | | |
| p. Reference fuel moisture, % (from table E) | | | | |
| Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change. | | | | |
| q. Aspect of projection point | | | | |
| r. Aspect of site location | | | | |
| s. Time | | | | |
| t. Elevation change<br>B = 1000'-2000' below site<br>L = ±1000' of site location<br>A = 1000'-2000' above site | B/L/A | B/L/A | B/L/A | B/L/A |
| u. Correction for projection point location (from table F) | | | | |
| v. Correction for site location (L) (from table F) | | | | |
| w. Fuel moisture correction, % (line u - line v) | | | | |
| x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side) | | | | |

***Figure 8.— con.***

**Plot Data**

To assure data validity it helps greatly to visualize the results; take the time to make a graph comparing the calculated and observed values of rate of spread and flame length.

Compile the observed and predicted rate of spread and flame length data in tabular form as shown in tables 2 and 3. Use the first column for identifying the data in each row by time period, plot number, etc. One column of observed values can be compared with several columns of predicted values, one for each fuel model.

**Table 2.**—Rate of spread data for tall grass fires taken by Paul Hefner in southeastern Oregon

| Observation No. | Observed rate of spread | Predicted rate of spread: Fuel model No. 1 | Fuel model No. 2 | Fuel model No. 3 |
|---|---|---|---|---|
| | Ft/min | | | |
| 1 | 88 | 36 | 18 | 76 |
| 2 | * | 4 | 3 | 6 |
| 3 | 132 | 98 | 41 | 120 |
| 4 | 374 | 266 | 139 | 292 |
| 5 | 132 | 66 | 29 | 76 |
| 6 | 495 | 733 | 279 | 612 |
| 7 | ** | 733 | 416 | 816 |
| 8 | 143 | 110 | 45 | 142 |
| 9 | 319 | 328 | 125 | 300 |
| 10 | 495 | 381 | 227 | 482 |
| 11 | *** | 327 | 278 | 531 |
| 12 | 3 | 3 | 2 | 4 |
| 13 | 126 | 72 | 47 | 128 |
| 14 | 240 | 381 | 163 | 381 |
| 15 | 352 | 150 | 150 | 292 |
| 16 | **** | 150 | 294 | 474 |
| 17 | 253 | 304 | 109 | 286 |
| 18 | 251 | 204 | 76 | 199 |
| 19 | 29 | 21 | 11 | 47 |

* trouble with ignition.
** no measurement, everyone too busy.
*** lost control due to fire whirl.
**** rate of spread not measured but flame length was.

**Table 3.**—Flame length data for tall grass fires taken by Paul Hefner in southeastern Oregon

| Observation No. | Observed flame length | Predicted flame length: Fuel model No. 1 | Fuel model No. 2 | Fuel model No. 3 |
|---|---|---|---|---|
| | Feet | | | |
| 1 | 12 | 3 | 5 | 11 |
| 2 | * | 1 | 2 | 3 |
| 3 | 12 | 4 | 6 | 13 |
| 4 | 18 | 7 | 11 | 19 |
| 5 | 15 | 4 | 6 | 11 |
| 6 | 25 | 13 | 17 | 31 |
| 7 | ** | 13 | 21 | 36 |
| 8 | 15 | 5 | 7 | 14 |
| 9 | 20 | 8 | 11 | 20 |
| 10 | 20 | 9 | 15 | 26 |
| 11 | *** | 8 | 16 | 26 |
| 12 | 3 | 1 | 2 | 3 |
| 13 | 10 | 3 | 7 | 6 |
| 14 | 15 | 9 | 13 | 23 |
| 15 | 28 | 5 | 11 | 19 |
| 16 | 36 | 5 | 16 | 23 |
| 17 | 28 | 8 | 11 | 20 |
| 18 | 18 | 6 | 9 | 16 |
| 19 | 12 | 2 | 4 | 9 |

* trouble with ignition.
** no measurement, everyone too busy.
*** lost control due to fire whirl.

In tables 2 and 3 we have displayed data taken by Paul Hefner (fire management officer, Burns District, BLM, Oregon) from fires burned in tall grass with some sagebrush during July and August 1980 in southeastern Oregon. The data were taken as a part of a burning program for range improvement. The first 14 observations were made in tall grass; the last 5 observations included 10 to 12 percent sagebrush in the area. Paul used fuel model 3 (Anderson 1982), which represents tall grass, for his predictions. (Fuel models and typical fuels are described in Anderson 1982.) The other two grass models, 1 and 2, have been included in the analysis to illustrate selection of the correct fuel model and to demonstrate the method for improving predictions.

The rate of spread data in table 2 are plotted in figures 9, 10, and 11. Note that the predicted value is indicated on the X axis, which is along the bottom. The observed values are indicated on the Y axis, along the side. Choose a scale (representative length of spaces on graph) that is appropriate for your data. The scales of the X and Y axes should be the same to aid interpretation of the data. Work with the data from one fuel model at a time. Then, for each observation there is a predicted value. Each predicted/observed pair of values will plot as a single point on the graph. To do this move along the X axis until the predicted value is found. Then go vertically from that point until the vertical distance representing the observed value is reached. At this point make a dot. Repeat until all other observations have been plotted for one fuel model. Repeat for the other fuel models. They can be plotted on the same graph if you choose, but the dots must be identified with a symbol so the different fuel models may be distinguished. We have plotted rate of spread on three separate graphs (fig. 9, 10, and 11) and flame lengths on three other graphs (fig. 12, 13, and 14).

Draw a diagonal line across the graph that represents perfect agreement between predicted and observed values. Your data probably will not lie on the line of perfect agreement; to find out how well the prediction matches the observed data, it is necessary to do a regression analysis. The regression analysis can be utilized to produce correction factors for improving future predictions in the same fuel type.

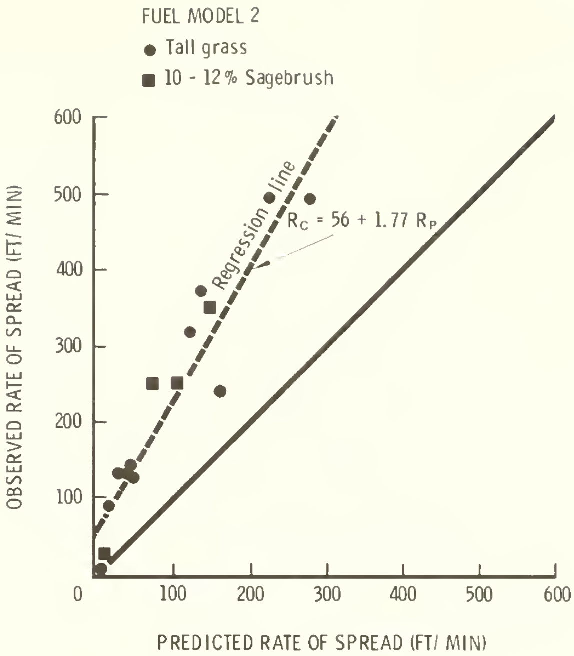


*Figure 10.—Observed rate of spread in tall grass compared to predictions made with fuel model 2 (Paul Hefner data).*

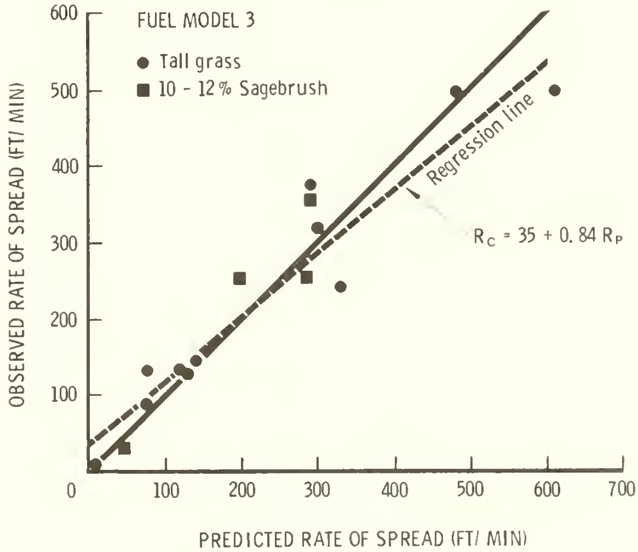


*Figure 11.—Observed rate of spread in tall grass compared to predictions made with fuel model 3 (Paul Hefner data).*

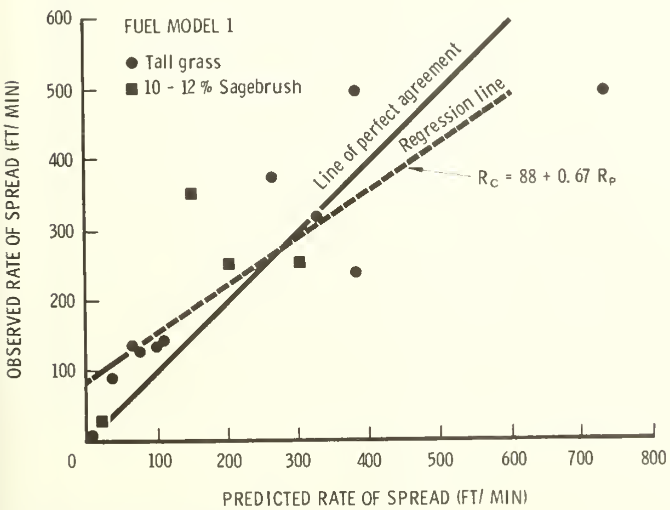


*Figure 9.—Comparison of observed rate of spread in tall grass, with predictions made with fuel model 1 (Paul Hefner data).*

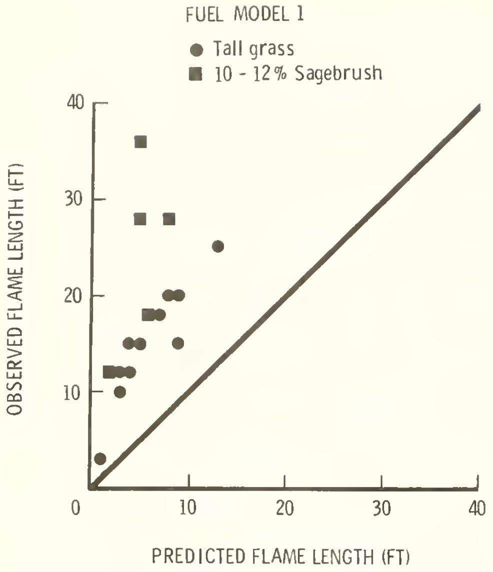


*Figure 12.—Observed flame length in tall grass compared to predictions made with fuel model 1 (Paul Hefner data).*

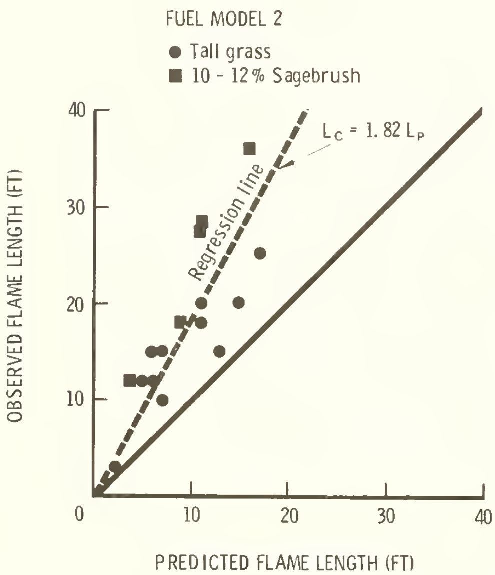


*Figure 13.—Observed flame length in tall grass compared to predictions made with fuel model 2 (Paul Hefner data).*

**Regression Analysis**

The theory behind the technique of regression analysis can be found in any statistics textbook so will not be dealt with here. Many small calculators, including the TI-59, provide a means of computing regression analysis; but you must use the Master Library Module rather than the NFDR/fire behavior module. Instructions are in the owner's manual.

The purpose of the regression analysis is to find the best correlation between the observed data and the predicted data. When this is done, the results can be used in the future to correct the predicted fire behavior to better represent the actual fire behavior. One of the results of the regression analysis will

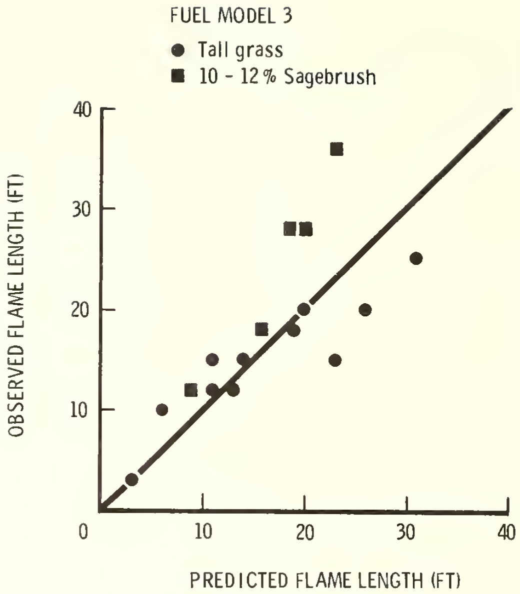


*Figure 14.—Observed flame length in tall grass compared to predictions made with fuel model 3 (Paul Hefner data).*

be a line on the graph that provides a visual display of the results. Another result is an equation of the following form:

$R_c = a + b R_p$

This equation contains two values of rate of spread, the predicted value, $R_p$, and what will become the corrected value, $R_c$. The coefficients a and b are constants that are determined by the regression analysis. With this equation a corrected rate of spread, $R_c$, can be determined from a predicted value and the constants a and b.

a is the Y intercept. a may be positive (+) or negative (−). It indicates where the line that is the best representation of your data will cross the Y axis.

b is the slope of the line. It should be positive and can be smaller or larger than 1. The closer it is to 1, the closer the regression line will parallel the line of perfect agreement.

When performing the regression analysis, be sure to enter the predicted values as the X values and the observed values as the Y values.

The data in table 2 produced these regression equations for fuel models 1, 2, and 3, with Paul Hefner's data:

| | |
|---|---|
| Fuel model 1 | $R_c = 88 + 0.67 R_p$ |
| Fuel model 2 | $R_c = 56 + 1.77 R_p$ |
| Fuel model 3 | $R_c = 35 + 0.84 R_p$ |

These equations are represented by dashed lines in figures 9, 10, and 11. To plot a line it is necessary to know two points along the line. One is given as the Y intercept. Note in figure 9 that the dashed line crosses the Y axis at a value of 88. To find another point, choose a convenient number along the X axis. For example:

let $R_p = 500$
then $R_c = 88 + (0.67)(500) = 88 + 335 = 423$

In other words, at $R_p = 500$, $R_c = 423$. Plot that point and draw a straight dashed line from it to the Y intercept (in this case 88). Extend the line across the graph.

Continue following the instructions of the regression analysis to determine the correlation coefficient (which is sometimes called the "$r^2$ value"). The correlation coefficient is a measure of how well your data groups around the regression line which you have just drawn. It will have a value between 0 and 1. The closer it is to 1, the nearer the points are to the regression line. Further explanation of regression analysis can be obtained from a statistics book.

Ideally, your data will produce a regression analysis with the Y intercept value near zero, the slope near 1, and the correlation coefficient near 1.

To select the most appropriate fuel model, arrange the coefficients in a table similar to that for Hefner's data for the three grass fuel models in table 4. (More elaborate statistics are unnecessary.) Primary consideration should be given to the correlation coefficient, ($r^2$). It is difficult to set firm rules on this, but $r^2$ values greater than 0.9 are excellent for this type of data, and values above 0.75 are acceptable. Data for fuel models that produce $r^2$ values less than 0.75 are probably not worth the development of correction factors.

**Table 4.**—Summary of results of regression analysis with Paul Hefner's rate of spread data

| Fuel model | Correlation coefficient $r^2$ | Y intercept a | Slope b |
|---|---|---|---|
| 1 | 0.84 | 88 | 0.67 |
| 2 | .94 | 56 | 1.77 |
| 3 | .94 | 35 | .84 |

If the $r^2$ is suitable, look for a low Y intercept. Y intercept values that are a small fraction of the mean of the expected range can be ignored, as done by Norum (1982). The slope coefficient then becomes a simple multiplicative correction such as reduction of all predicted values by 80 percent. Repeat the analysis with flame length data. Although you can use different fuel models to predict rate of spread and flame length as Norum (1982) indicates, it is much less troublesome if you can find one model for both.

A summary of the results of the regression analysis with Paul Hefner's data is shown in table 4. Inspection of figures 9, 10, and 11, and table 4 leads to the choice of fuel model 3. It has the highest correlation coefficient, the same as model 2. It has the smallest Y intercept and a slope closest to 1.0. The dashed line in figure 11 can be seen to lie much closer to the solid line than for the other fuel models in figures 9 and 10. In fact, model 3 fits well enough that no correction to the rate of spread prediction is justified.

The flame length data as shown in figures 12, 13, and 14 also support the selection of fuel model 3 (fig. 14) as the best choice.

Based on all criteria then, fuel model 3 best represents the fuel and fire situations observed by Paul Hefner in tall grass in eastern Oregon.

**Calibration**

Suppose that you cannot find a model that produces accurate predictions. That is, predicted values are consistently high or consistently low. Such a case is exemplified by the data from fuel model 2 in figure 10. The model consistently underpredicts the observed values, but they are tightly grouped all along the regression line with a correlation coefficient of 0.94, the same that model 3 gave. This indicates that fuel model 2 is consistent, even though it is not accurate. In such a case the regression equation can be utilized to correct the prediction. The regression equation for Hefner's data with fuel model 2 is:

$$R_c = 56 + 1.77\,R_p$$

Let us examine the process. Norum showed that if the Y intercept was near zero, it was only necessary to multiply the predicted value by the slope value to get a better estimate of the observed or actual value. This may not always be the case and it may be necessary to include the correction for the Y intercept. Plot the corrected predictions versus the observations to see if this is necessary.

First multiply all predicted values by the slope correction, 1.77, and replot the data. The calculations are shown in table 5. A plot of the data is shown in figure 15.

The corrected predictions in figure 15 are better; the data points parallel, but still do not straddle the line of perfect agreement. The adjustment with the regression equation is completed by adding the Y intercept value. The complete correction, $R_c$, is shown in table 5 and plotted in figure 16. This figure shows that the predictions are now as accurate as these data will allow. For comparison, the regression equation for fuel model 3 was utilized to correct the data and the corrected data for both models are shown in figure 16. Visually it would be hard to say which set of data points lies closest to the line of perfect agreement. Fuel model 2 with calibration would be acceptable if fuel model 3 did not exist.

**Table 5.**—Tabulated calculations of corrections to rate of spread predictions utilizing fuel model 2 with Paul Hefner's data

| Observation No. | $R_{ob}$ | $R_p$ | $1.77R_p$ | $R_c = 56 + 1.77R_p$ |
|---|---|---|---|---|
| 1 | 88 | 18 | 32 | 88 |
| 2 | * | 3 | 5 | 61 |
| 3 | 132 | 41 | 72 | 128 |
| 4 | 374 | 139 | 246 | 302 |
| 5 | 132 | 29 | 51 | 107 |
| 6 | 495 | 279 | 494 | 550 |
| 7 | ** | 416 | 736 | 792 |
| 8 | 143 | 45 | 80 | 136 |
| 9 | 319 | 125 | 221 | 277 |
| 10 | 495 | 227 | 402 | 458 |
| 11 | *** | 278 | 492 | 548 |
| 12 | 3 | 2 | 4 | 60 |
| 13 | 126 | 47 | 83 | 139 |
| 14 | 240 | 163 | 288 | 344 |
| 15 | 352 | 150 | 266 | 322 |
| 16 | **** | 294 | 520 | 576 |
| 17 | 253 | 109 | 193 | 249 |
| 18 | 251 | 76 | 134 | 190 |
| 19 | 29 | 11 | 20 | 76 |

* trouble with ignition.
** no measurement, everyone too busy.
*** lost control due to fire whirl.
**** rate of spread not measured but flame length was.

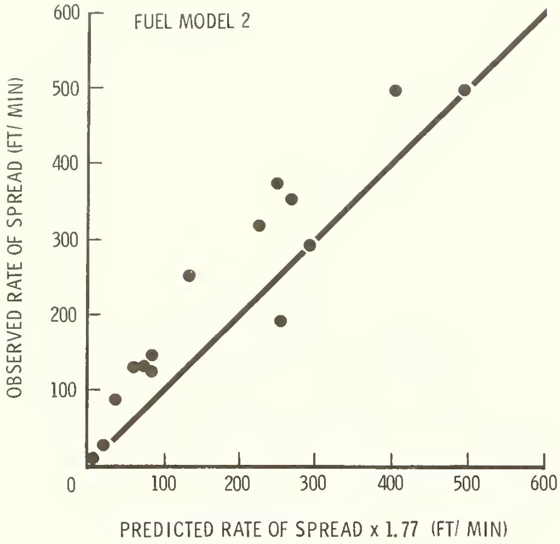


***Figure 15.—Rate of spread predictions for fuel model 2 corrected by only the slope of the regression equation (Paul Hefner data).***

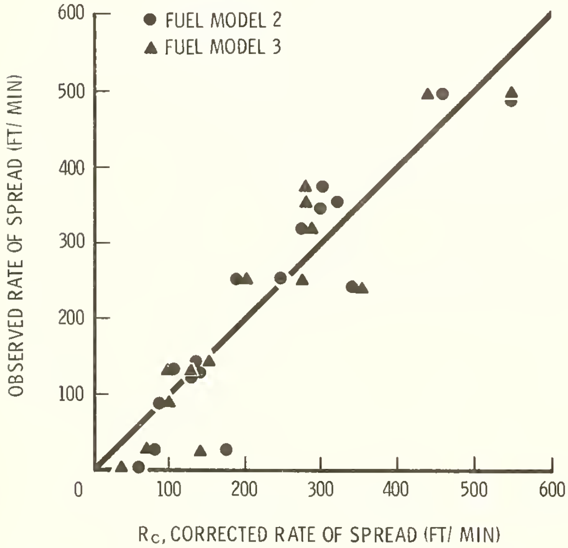


***Figure 16.—Observed rate of spread compared to predictions corrected by both the slope and the Y intercept of the regression equations for fuel models 2 and 3 (Paul Hefner data).***

If desired, the same process can be used on the flame length data; however, the desire for better accuracy must be balanced with the practicality of keeping the prediction methods simple enough to be useful.

Before we leave Hefner's data there are some significant points that should be discussed. There was trouble with ignition for data that plotted near the origin, indicating that burning conditions were marginal. By contrast, when the predicted flame lengths were 36 ft (observation 7) with rate of spread predicted to be 816 ft/min, no observations were taken because everyone was too busy controlling the fire. Also, when the flame length was 26 ft and the predicted rate of spread 531 ft/min (observation 11), control of the fire was lost due to a fire whirl. These observations are consistent with interpretations of fire behavior expressed in figure 7 and it is gratifying that the prediction methods are capable of matching the data throughout this range of fire behavior.

Another interesting interpretation is that the data taken with 10 to 12 percent sagebrush in the area seemed to show no effect upon rate of spread. This is concluded from the intermingling of data points with or without sagebrush. This is what would be expected; with that small amount of sage, the grass can carry the fire around it. The flame length data, however, produce a different interpretation. In figure 14, the data points representing the fires with 10 to 12 percent sagebrush have significantly higher observed flame lengths than the pure grass. Again, this would be expected as the fires flare up when burning through the brush concentrations.

**Calibration Without Regression Analysis**

It is possible to obtain a correction factor for rate of spread or flame length without a regression analysis if the data points do not have too much scatter. The importance of having data over the entire range of conditions, from barely burning to barely controllable, cannot be stressed too strongly if the analysis is to be meaningful.

To illustrate the method we will use the flame lengths calculated with fuel model 2 from Paul Hefner's data shown in figure 13. (All points will be considered the same type fuel.) Instead of using regression analysis to determine the regression equation, we will draw a line through the points by eye and develop a calibration factor from that. In this case the data seem to trend through zero so there is no need for a Y intercept constant.

Use a transparent plastic ruler or straightedge. Pass one side through the origin and aline the edge so it passes as closely as possible through the remaining points, with approximately as many above the line as below. Draw a line from the origin through the points. Determine the slope of the line by taking the ratio of an observed and a predicted value on the line near its high end. For instance, in figure 13 at $R_p = 20$, $R_{ob} = 37$. The ratio of observed to predicted is then 37/20 or 1.85. For more accurate predictions of flame length in this fuel type, use 1.85 as a correction factor. For example, a predicted flame length of 10 ft will be corrected to 18.5 ft, a much better estimate.

If the points do not trend through the origin, just lay the straightedge along the apparent trend line, so the points group as closely as possible to it. This is what the mathematics of regression analysis does for you—but your eye can do very well also! In this case, measure off the Y intercept and use this value for the number "a" as explained in the section before on spread rate prediction. Subtract this value (which may be negative) from the "observed" value before taking the ratio to determine the slope of the line. Correction of predictions must now use both the slope and the Y intercept as explained in the calibration section.

**Adjusting Moisture of Extinction**

One of the factors used in the fire model that is not determined from fuel conditions, but only estimated, is the moisture of extinction. This is not a critical value when the fuels are dry, but when the fuel moisture is close to the moisture of extinction the predicted rate of spread can be significantly different from the observed. In fact, in some cases a prediction of no spread will be made when the fire does burn or the reverse may be true. This can be a serious problem for predicting conditions for prescribed burning, which is often done under marginal burning conditions. When a better moisture of extinction is determined, it can be used with the TI-59 fire behavior CROM by inserting it in register 25.

The process will be illustrated with data taken by Collin Bevins in western Washington logging slash during the summer of 1975. Moisture of extinction probably depends most strongly on the fuel loading, size, and arrangement. Bevins inventoried the fuel in size classes 3 inches in diameter and smaller (table 6). The fuel loadings 3 inches and under were similar to those of fuel model 11 (except for Unit S-38L which was not used in the analysis). The moisture content and other observed data are shown in table 7.

The moisture of extinction of fuel model 11 is 15 percent. This means that fuel arrays with fine fuel moisture greater than 15 percent will not be predicted to burn. Note in table 7 that only units S-45L and S-38U were sufficiently dry to be expected to burn on this basis. This is confirmed in figure 17 where all the fires except two were predicted not to burn. The solution to this problem is to increase moisture of extinction. If the model predicts fires to burn when they wouldn't burn, then moisture of extinction should be decreased. But for these data we will increase the moisture of extinction used for predicting fire spread rate and see how the predictions are changed.

Moisture of extinction, or $M_x$, was increased to 20 percent and to 25 percent, and new predictions were made with fuel model 11. To do this with the TI-59, select fuel model 11 and then enter the new moisture of extinction on the keyboard, which will appear in the display. Press STO 25 and the number being displayed will be stored in register 25. To check if that happened, hit RCL 25 and the moisture of extinction will be displayed. RCL does not erase the stored value. If you wish to evaluate more than one value of moisture of extinction, enter the environmental conditions and make a calculation with the first value of $M_x$, then change $M_x$ and repeat the calculation with the same environmental conditions. It is not necessary to reenter them.

The results of this process are shown in table 8 for $M_x = 15$, 20, and 25 percent, and plotted in figures 17, 18, and 19. The results are readily apparent; in figure 18, only two fires were predicted not to burn, but the prediction is still not satisfactory. In figure 19, with $M_x = 25$ percent, one fire is predicted not to burn, but the others correlate reasonably well with the observed values. Note that the predicted rate of spread for the two fires with drier fuels did not change much when $M_x$ was changed. The prediction for the wettest one did improve somewhat. A regression analysis with $M_x = 25$ percent gives a correlation coefficient of 0.73. The regression line is plotted in figure 19:

$$R_c = 0.06 + 1.26 R_p$$

**Table 6.**—Fire model inputs: fuelbed loadings and bulk depths

| Plot ID | | | Location[1] | Needle load | 1-h woody load | 10-h load | 100-h | Net load | Bulk depth |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *Lb/ft²* | | | | | *Ft* |
| I | 14 | U | SRD | 0.0003 | 0.0314 | 0.1389 | 0.3041 | 0.4747 | 0.70 |
| I | 14 | L | SRD | .0030 | .0597 | .1283 | .4703 | .6613 | 1.01 |
| S | 44 | U | SRD | .0000 | .0216 | .2499 | .3948 | .6663 | .12 |
| S | 45 | U | SRD | .0220 | .0396 | .1800 | .5845 | .8261 | .50 |
| S | 45 | L | SRD | .0138 | .0605 | .2095 | .4764 | .7602 | .93 |
| SO | 38 | U | SRD | .0150 | .0188 | .0927 | .1846 | .3111 | .74 |
| SO | 38 | L | SRD | .0801 | .0746 | .2685 | .3225 | .7457 | .54 |
| KRD | 1 | E | KRD | .0018 | .0170 | .1226 | .2493 | .3907 | .29 |
| KRD | 1 | W | KRD | .0055 | .0207 | .1097 | .2208 | .3567 | .43 |
| KRD | 4 | E | KRD | .0014 | .0115 | .1465 | .1791 | .3385 | .53 |
| KRD | 4 | W | KRD | .0023 | .0335 | .1809 | .9128 | 1.1295 | .62 |

[1]SRD: Soleduck Ranger District, Olympic National Forest, Region 6, western hemlock.
KRD: Klamath Ranger District, Winema National Forest, Region 6, ponderosa pine.

**Table 7.**—Collin Bevins' rate of spread and environmental data for fires in logging slash in western Washington

| Unit | | | $R_{ob}$ | Fuel moisture 1-h | 10-h | 100-h | Wind | Slope |
|---|---|---|---|---|---|---|---|---|
| | | | *Ft/min* | *Percent* | | | *Mi/h* | *Percent* |
| I | 14 | U | 3.9 | 20.9 | 16.4 | 9.3 | 4.9 | 40 |
| I | 14 | L | 3.2 | 28.0 | 21.7 | 25.2 | 9.2 | 44 |
| S | 45 | U | 4.7 | 20.2 | 14.0 | 18.4 | 5.0 | 24 |
| S | 45 | L | 14.9 | 11.2 | 13.6 | 36.9 | 1.6 | 82 |
| S | 38 | U | 1.8 | 8.2 | 11.2 | 16.2 | 3.2 | 32 |
| KRD | 1 | E | 1.1 | 14.6 | 18.0 | 26.2 | 1.2 | 0 |
| KRD | 1 | W | .6 | 14.6 | 21.9 | 26.0 | 1.2 | 0 |
| KRD | 4 | E | 3.8 | 15.5 | 34.5 | 24.1 | 3.0 | 0 |
| KRD | 4 | W | 2.5 | 14.6 | 28.1 | 32.5 | 2.5 | 0 |

**Table 8.**—Calculated rate of spread values for Bevins' data using fuel model 11 with moisture of extinction, $M_x$, values set at 15 percent, 20 percent, and 25 percent

| Unit | | | $R_p$ at $M_x = 15\%$ | $R_p$ at $M_x = 20\%$ | $R_p$ at $M_x = 25\%$ |
|---|---|---|---|---|---|
| | | | (tabulated values are rate of spread, ft/min) | | |
| I | 14 | U | 0 | 0 | 4.4 |
| I | 14 | L | 0 | 0 | 0 |
| S | 45 | U | 0 | 1.1 | 4.4 |
| S | 45 | L | 4.4 | 7.7 | 7.7 |
| S | 38 | U | 4.4 | 5.5 | 5.5 |
| KRD | 1 | E | 0 | 1.1 | 1.1 |
| KRD | 1 | W | 0 | 1.1 | 1.1 |
| KRD | 4 | E | 0 | 1.1 | 2.2 |
| KRD | 4 | W | 0 | 1.1 | 2.2 |

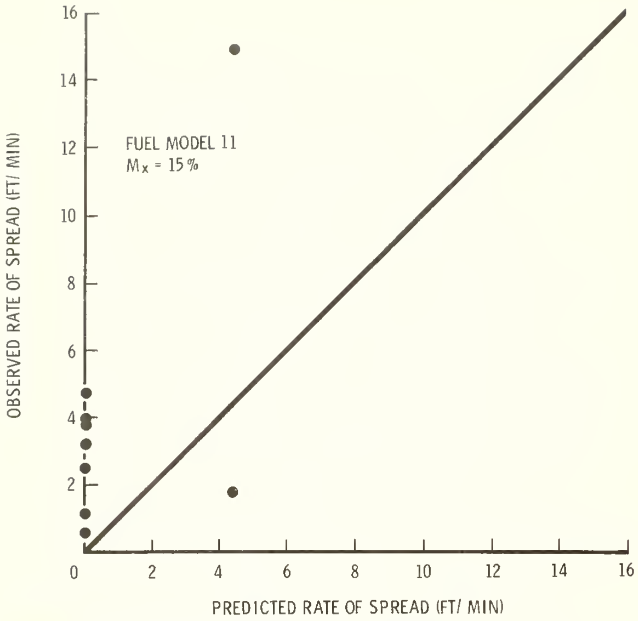


*Figure 17.—Observed rate of spread in logging slash compared to predicted rate of spread with fuel model 11, with moisture of extinction set at 15 percent (Collin Bevins data).*

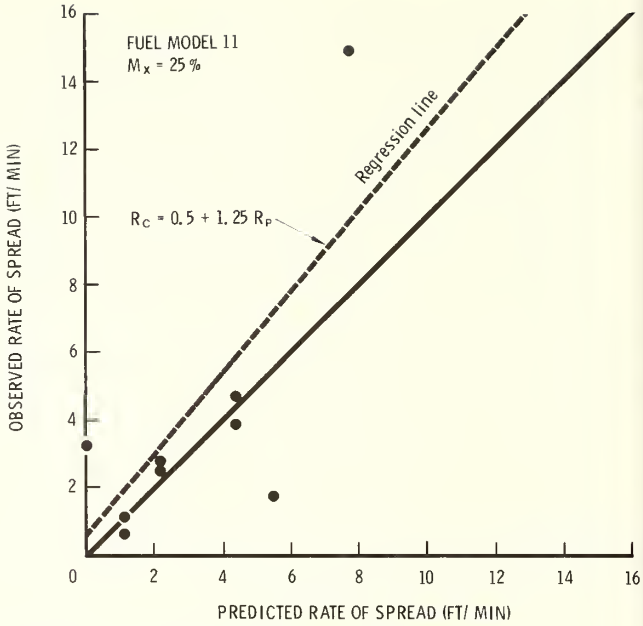


*Figure 19.—Observed rate of spread in logging slash compared to predicted rate of spread with fuel model 11, with moisture of extinction set at 25 percent (Collin Bevins data).*

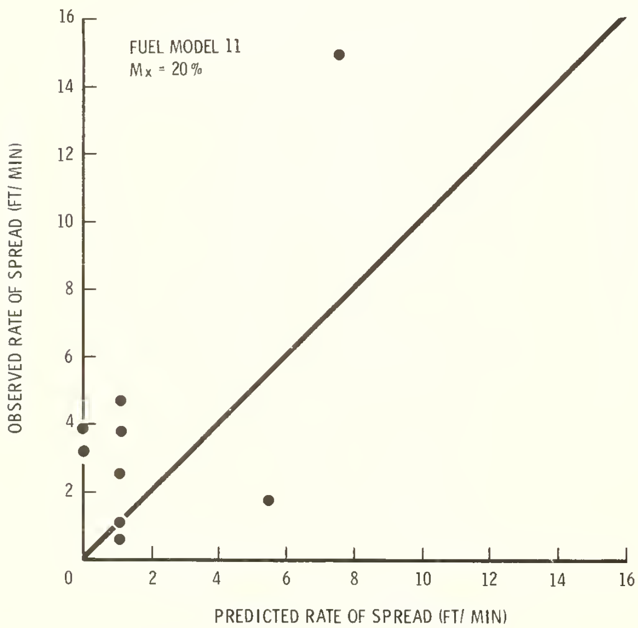


*Figure 18.—Observed rate of spread in logging slash compared to predicted rate of spread with fuel model 11, with moisture of extinction set at 20 percent (Collin Bevins data).*

For future work in similar logging slash, a better estimate of spread rate can be made with fuel model 11 by changing the moisture of extinction from 15 percent to 25 percent. Why should the moisture of extinction be nearly doubled in these fuels? Our explanation follows.

The logging slash areas of western Washington contain far more material in the large size classes and in the form of broken and scattered debris that do not show up in an inventory of fuel in the 3-inch and smaller diameter size classes. This provides a more continuous cover of organic material than fuel model 11 was designed to represent as a light slash fuel model. Consequently, at higher moisture contents, the fire is able to sustain itself; whereas if it encountered discontinuities at moisture contents above 15 percent, it would probably not spread. The additional amounts of logging slash also provide enough extra organic material to produce larger flame lengths than predicted by fuel model 11 even though spread rate is still controlled by the representation of fine fuels in this model.

**Interpreting a Small Quantity of Data**
(from test situation 2 or 3)

An example of situation No. 2 (weather observed prior to the fire) is taken from the O'Keefe Creek prescribed fire conducted in western Montana in October 1979. The burn was conducted to study the effect of fire on shrub production in a game management area. The fuels consisted primarily of shrubs with interspersed grass. The shrubs were mostly ninebark and ceanothus. The ninebark leaves had changed color, but were still attached. A test fire was conducted in a small area before general ignition. The test fire confirmed that the shrubs would burn.

The burn was conducted by firing successive strips from the top of the ridge to the base. Weather observations were made prior to ignition and are shown in table 9. Rate of spread was determined by measuring the widths of the strips (from a distant point) with a rangefinder and dividing this distance by the time it took fire to cross the strip. Six strips were measured this way. Flame lengths were not measured in these observations. The results are shown in table 10 marked group A.[4]

**Table 9.**—O'Keefe Creek fire environmental conditions

| Item | Value |
|---|---|
| Shade factor | 0 |
| Temperature | 60°F |
| Relative humidity | 29% |
| 1-hr fuel moisture | 5.5% |
| 10-hr fuel moisture | 10% |
| 100-hr fuel moisture | 10% |
| Live fuel moisture | 60% |
| Midflame windspeed | 7 mi/h |
| Slope | 17%[1] |

[1]Most fires burned on steeper slopes. Constant 17-percent value contributed to underprediction of spread rate for group A.

**Table 10.**—Results of O'Keefe Creek fire

| Group A | Predicted values | | Observed values |
|---|---|---|---|
| Fuel model | 5 | 2 | |
| Proportion, % | 80 | 20 | |
| Rate of spread, ft/min | 66 | 85 | 30, 180, 50, 60, 142, 75 |
| Flame length, ft | 10 | 9 | |
| Composite R utilizing two-fuel-model concept 70 ft/min | | | Average observed 90 ft/min<br>Standard deviation 58 |

| Group B | Predicted values | Observed values |
|---|---|---|
| **Upper slope** | | |
| Rate of spread* ft/min | 56 | 62 |
| Flame length, ft | 8 - 9 | 10 |
| **Midslope** | | |
| Rate of spread* ft/min | 77 | 56 |
| Flame length, ft | 9 - 10 | 9 |
| **Lower slope** | | |
| Rate of spread* ft/min | 69 | 44 |
| Flame length, ft | 9 - 10 | 8 |

*Weighted for two fuels.

A second group[5] marked three transects 1 chain in length using 6-ft stakes inserted prior to the burn. These data are also shown in table 10.

Both groups elected to use the two-fuel-model concept to characterize the fuels and spread rate.

The analysis consists simply of comparing the predicted rate of spread with the observed to see if reasonable estimates could be made. The predicted values of group A for fuel models 5 and 2 ranged from 66 to 85 ft/min. The weighted average by the two-fuel-model concept was 70 ft/min. Observed values in these areas averaged from 30 to 180 ft/min, with a mean of 90 ft/min and a standard deviation of 58 ft/min. These predictions tended to underestimate the observed rate of spread. Group B, working with measured transects on gentler slopes, measured slower spread rates, ranging from 44 ft/min to 62 ft/min. The predictions were closer, ranging from 56 ft/min to 77 ft/min. This amount of scatter in data between the two groups and within the same fire is not unusual. In both cases, the results are sufficiently accurate to characterize rate of spread for this type of prescribed burning.

The flame length data taken by group B show remarkably good agreement between predicted and observed. This is as important to prescribed burn planning as rate of spread. (It should be remembered that the data were taken from strip fires with wide spacing. You cannot expect these results with center firing and edge burning.)

## Restricted Accessibility

Restricted accessibility will probably take place on a wildfire or an unplanned, prescribed fire. It is assumed that the fire behavior is rather severe, or the fire is located in rough terrain or a remote location. Because of the difficulty of access, detailed data collection as described for accessible fires may not be possible. The procedures described in this section are designed to test predictions rather than to develop correction factors.

### PREDICTIONS

Fire behavior should be predicted by the means of S-590 Fire Behavior Officer techniques described by Rothermel (1983). Output should include a map of the expected location of the fire by time and a fire characteristics chart (Andrews and Rothermel 1982) that shows the probable intensity of the fire. On a large fire, it will probably not be possible to verify or even predict growth along the entire perimeter. In fact, some of the line may be secure. For verification purposes, determine the section of line that can be expected to be most active, and where suppression action has not started.

Predictions made several hours in advance from forecasted weather should anticipate the time of day when the fire will begin to make a significant run and when it will probably stop spreading. The methods cited are designed to predict the rate of spread of the active part of the fire, and since wildfires often spread by a series of runs with rather dormant periods between, verification over long periods of time must account for this variable behavior. For instance, many fires spread faster in the afternoon, but normally the fire position is only updated once a day. Because 90 percent of the growth during the 24-hour period may have occurred in 2 or 3 hours, the rate of spread calculated for the peak burning period must be limited to those hours, or fire growth will be severely overpredicted.

[4]Report by R. C. Rothermel, titled, "Calculations of fire behavior on the O'Keefe Creek prescribed fire," on file at the Northern Forest Fire Laboratory, Missoula, Mont.

[5]Report by Ron Prichard, titled, "Observations of fire behavior on the O'Keefe Creek prescribed fire," on file at the Northern Forest Fire Laboratory, Missoula, Mont.

## OBJECTIVES

It is not likely that you will be able to take all the data shown on the fire observation data sheet although the sheet may still be useful for organizing data. Because fire growth has already been predicted and recorded, the primary purpose of the observations is to locate the position of the fire at times that coincide with the forecast and to take sufficient weather and fuels observations to compare the actual conditions with the predicted. If circumstances are favorable, and you are able to gather all of the data needed on the fire observation worksheet, then verify predictions as described in situation 3 for accessible fires.

### CAUTION

Observations of fire behavior under severe conditions in remote areas can be very difficult. Under no circumstances should safety be compromised for the purpose of collecting data. Wilson (1977) describes dangerous conditions on wildfires that have trapped firefighters.

**Equipment**

Do not burden yourself with excessive equipment; carry a small pack that will not encumber your movement in rough terrain. Carry a belt weather kit and a small 35-mm camera. A small handheld dictation recorder with an extra battery and tapes is far superior to written notes because you can observe the fire and be much more descriptive. A reliable watch is also needed. Stopwatches are usually not needed on a wildfire; it is better to record the time of day so that your observations can be coordinated with weather events and the observations of others. A rangefinder and an instrument for measuring slope should also be considered.

**Observing Fire Growth**

On fires expected to spread on a slope in rough terrain, the best vantage point may be a ridgetop on the opposing slope. Record the position of the fire by sketching lines on a map or on a transparent overlay covering a map. If the fire begins a significant move, note the time and position when it began. Estimate fire position at periodic time intervals. If the weather changes, or the fire moves into a different slope or into a new fuel type, make note of this; to the extent possible note the new windspeed and direction and fuel type. Note the direction of fire spread with respect to slope. Note the flame lengths. A photograph can help in recording flame length. Do not choose to record only the longest flames, or the shortest, but an average maximum along the line.

Occasionally take pictures of significant behavior—not only the severe events, but also the general patterns. Record the picture number and verbally describe what is being photographed. Pictures without a corresponding description of time, place, and fire situation are not good sources of data. If there are fire control forces working in the area, make note of their effectiveness.

From a good vantage point it may be possible to photograph the growth of a section of the fire at periodic intervals. A 35-mm camera mounted on a tripod is recommended. Depending on the fire spread rate, take pictures at 5-, 10-, or 15-minute intervals (Britton and others 1977).

**Weather**

Someone should be monitoring the general weather, either at a mobile weather station, at a lookout, or with portable weather stations set up at peripheral locations. Periodic observations should be made as needed to determine whether or not the forecasted weather materializes. Near the fire itself on the same slope, aspect, and shade conditions as the fire, use the belt weather kit to monitor the temperature, humidity, windspeed, and wind direction. Indicate which wind readings are taken with a handheld anemometer, to avoid confusing them with anemometer readings taken at 20 ft. Take wet bulb and dry bulb temperatures at least once an hour, or when there is a noticeable change in fire activity. Determine relative humidity and record all values.

**Fuels**

Observe the general vegetative cover and identify the most appropriate fuel model. The key to choosing a fuel model is identifying the stratum that is carrying the fire. Is it burning primarily in the needle litter, or in the dead and downed material, or the grasses, or the shrubs? If the fire is moving through nonuniform fuels, periodically flaring when encountering fuel concentrations, note the types of fuels that are carrying the fire in general and the types of fuels that are causing the flareups. As the fire proceeds, try to determine the influence of the green fuels. Are they inhibiting the spread? Or are they burning vigorously and helping the fire spread?

A change in the weather, such as higher temperature or lower humidity, can dry the fine fuels and cause the fire to move into a more flammable stratum. Fire will move fastest in the most porous fuels if it can sustain itself there. Wind is especially important for causing change; it can move the fire from a litter stratum into the more porous grass stratum. A change from a litter fuel model to a grass model would then be required.

**Slope**

Decide ahead of time how you will determine slope. If good contour maps are available, your field observations may be limited to sketching where the fire is and confirming that the maps are not seriously in error. If you choose to use a handheld instrument it may be easier to determine the slope after the fire has passed over the area and things have cooled down. Follow the guides for determining slope given in the section on accessible fires.

**Severe Fire**

Make note of the time that torching of trees begins, or when actual sustained crowning begins and ends. If this is happening, there is a good chance that spotting may be occurring. Watch for firebrands and spotting. If the fire is crowning, the belt weather kit may not be much help for recording windspeed. In this case the revised Beaufort scale (Jemison 1934) shown in figure 20 may be helpful. Record spotting events as described in the section on accessible fires.

**Termination of Spread**

If the fire slows down and stops, try to determine why. Did it burn into different fuel? Did the wind stop? Did it encounter a natural barrier? Did higher humidities and lower temperatures of evening seem to affect it?

MODIFIED BEAUFORT SCALE
FOR ESTIMATING 20-FOOT WINDSPEED

| Wind class | Range of speeds mi/h | Nomenclature |
|---|---|---|
| 1 | ≤ 3 | Very light - smoke rises nearly vertically. Leaves of quaking aspen in constant motion; small branches of bushes sway; slender branchlets and twigs of trees move gently; tall grasses and weeds sway and bend with wind; wind vane barely moves. |
| 2 | 4 - 7 | Light - trees of pole size in the open sway gently; wind felt distinctly on face; loose scraps of paper move; wind flutters small flag. |
| 3 | 8 - 12 | Gentle breeze - trees of pole size in the open sway very noticeably; large branches of pole-size trees in the open toss; tops of trees in dense stands sway; wind extends small flag; a few crested waves form on lakes. |
| 4 | 13 - 18 | Moderate breeze - trees of pole size in the open sway violently; whole trees in dense stands sway noticeably; dust is raised in the road. |
| 5 | 19 - 24 | Fresh - branchlets are broken from trees; inconvenience is felt in walking against wind. |
| 6 | 25 - 31 | Strong - tree damage increases with occasional breaking of exposed tops and branches; progress impeded when walking against wind; light structural damage to buildings. |
| 7 | 32 - 38 | Moderate gale - severe damage to tree tops; very difficult to walk into wind; significant structural damage occurs. |
| 8 | ≥ 39 | Fresh gale - surfaced strong Santa Ana; intense stress on all exposed objects, vegetation, buildings; canopy offers virtually no protection; wind flow is systematic in disturbing everything in its path. |

*Figure 20.—Modified Beaufort scale of wind force (Jemison 1934).*

**Identify Data**

Carefully identify your data with the date, time, fire name, your name, division, sector, etc. Be very careful with photographs. Do not leave partially exposed rolls in the camera. Send all film to be processed promptly. When it returns, label it immediately.

**ANALYSIS OF DATA**

This type of testing does not lend itself to rigorous statistical analysis. It can, however, indicate whether your fire behavior prediction techniques are working, and if not, what the problem might be. For situation 2 use the map to compare predicted and actual positions over the time that the prediction was made. Compare the fire severity with that indicated on the fire characteristics chart. An example of comparison of predicted and actual fire growth as done by Larry Keown on the Independence Fire in 1979 was reported by Andrews (1980) and is shown in figure 21. The flame length is the clue for predicting severity, and it should be compared with both the observed flame lengths and the propensity for torching, crowning, and spotting. An example of such a comparison prepared by Ed Mathews for the Montana Department of Natural Resources on the Barker Fire in 1979 was reported by Andrews (1980) and is repeated below:

## Barker Fire

An FBO was assigned to the Barker Fire in Montana in August 1979. The situation was quite different from that encountered on the Independence Fire. The FBO arrived with a Class I overhead team when the fire was 800 acres and behaving erratically. Hot dry weather through the month of July had dried fuels to well below normal levels. Winds were blowing at 20 to 30 mi/h, with gusts measured to 50 mi/h. It didn't take a fire behavior model to tell the FBO that there was a problem. This example is included to illustrate that, although the fire model is designed for surface fires and does not quantitatively predict the behavior of a fire that is crowning and spotting, it does indicate the potential of severe fire behavior.

A correlation between predicted flame length and fire suppression interpretations is given in figure 7. In this case the calculations that the FBO did when he arrived on the fire resulted in a flame length prediction of 21 ft. This falls well into the fourth category of interpretations: "Crowning, spotting, and major fire runs are probable. Control efforts at the head of the fire are ineffective." This was certainly the case.

The predicted flame length for Monday was 9 ft. According to figure 7, this indicates that "Fires may present serious control problems, i.e., torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective." Compare this prediction to what was reported in a fire behavior summary, "Fire intensity was significantly less than on Sunday. Spotting and crowning still occurred and extremely hot areas kept forces out of areas in front of the fire." By Monday evening the fire size was estimated to be 2,460 acres.

Only about 30 acres burned on Tuesday. According to the Fire Behavior Summary, "Fireline mopup and line construction are proceeding well on Divisions I and II. Occasional flareups are occurring on these divisions, but are being handled OK by crews on the line." The predicted flame length for this day was 3 ft. The actual situation compared favorably with the interpretation given in figure 7. "Fires can generally be attacked at the head or flanks by persons using hand tools. Handlines should hold the fire."

If the forecasted weather did not occur, the data can still be used for analysis as described for situation 2 or situation 3.

**Situation 2.**—Forecasted weather did not occur. Use the weather that was observed at the time of each run to make a new prediction. In some cases, the change in weather may mean that a different fuel stratum would carry the fire and a different fuel model should be used. Compare this new prediction with the actual fire behavior, both as to spread on a map and intensity as described above.

**Situation 3.**—If things went so well that you could fill out a fire observation sheet and know the precise location of the fire, proceed with the analysis described for accessible fires.

If all assumptions of weather, fuels, and initial fire position are felt to be reasonable, and the prediction did not match the actual as closely as expected, the observations can be reviewed to try to locate the problem.

Was the slope properly accounted for? Did the fire move on the slope in the way it was expected? In other words, did it go upslope, downslope, cross-slope, contrary to what was anticipated?

Were the fuels properly identified? Did the chosen fuel models match the stratum in which the fire was burning? Did the fire stay in the litter until the wind picked up or the humidity dropped, causing it to burn in a more flammable fuel stratum? Was the green fuel inhibiting the fire? If so, it might have been at a higher moisture content than was estimated, or a model with more green fuel might be required. Was there so little dead fuel and so much green fuel that the fire just would not spread?

Was fuel nonuniformity a problem? Was it primarily spreading in one stratum and flaring up when it encountered fuel accumulations? Or was it flaring up along the line as it moved from stratum to stratum. If this was the case, then the two-fuel-model concept is appropriate.

Was there short-range spotting that caused the fire to move faster than was predicted? Was there long-range spotting that was causing new starts well ahead of the fire, causing a ragged line and preventing a line of fire spread as anticipated?

Was crowning occurring and causing the fire to spread faster than was predicted for the surface fire? If so, try to determine the ratio of crown fire spread rate to that predicted for the surface fire.

Was the midflame windspeed correctly predicted? This cannot be exactly known, but the handheld anemometer can give a good indication of midflame windspeed if the fire is moving through surface fuels. Compare measurements to the prediction, and see what would happen if the predicted windspeed had been equal to the observed midflame windspeed. Was the wind direction correctly predicted for the observed section of the line?

To help answer these questions, use data collected on the fire to see what the fire prediction system predicts with observed data rather than forecast data.

Inaccessible fires are hard to deal with and you will often be frustrated in your attempts at verification. Nevertheless, worthwhile experience in fire behavior analysis will be gained as you attempt to identify the elements of the problem.

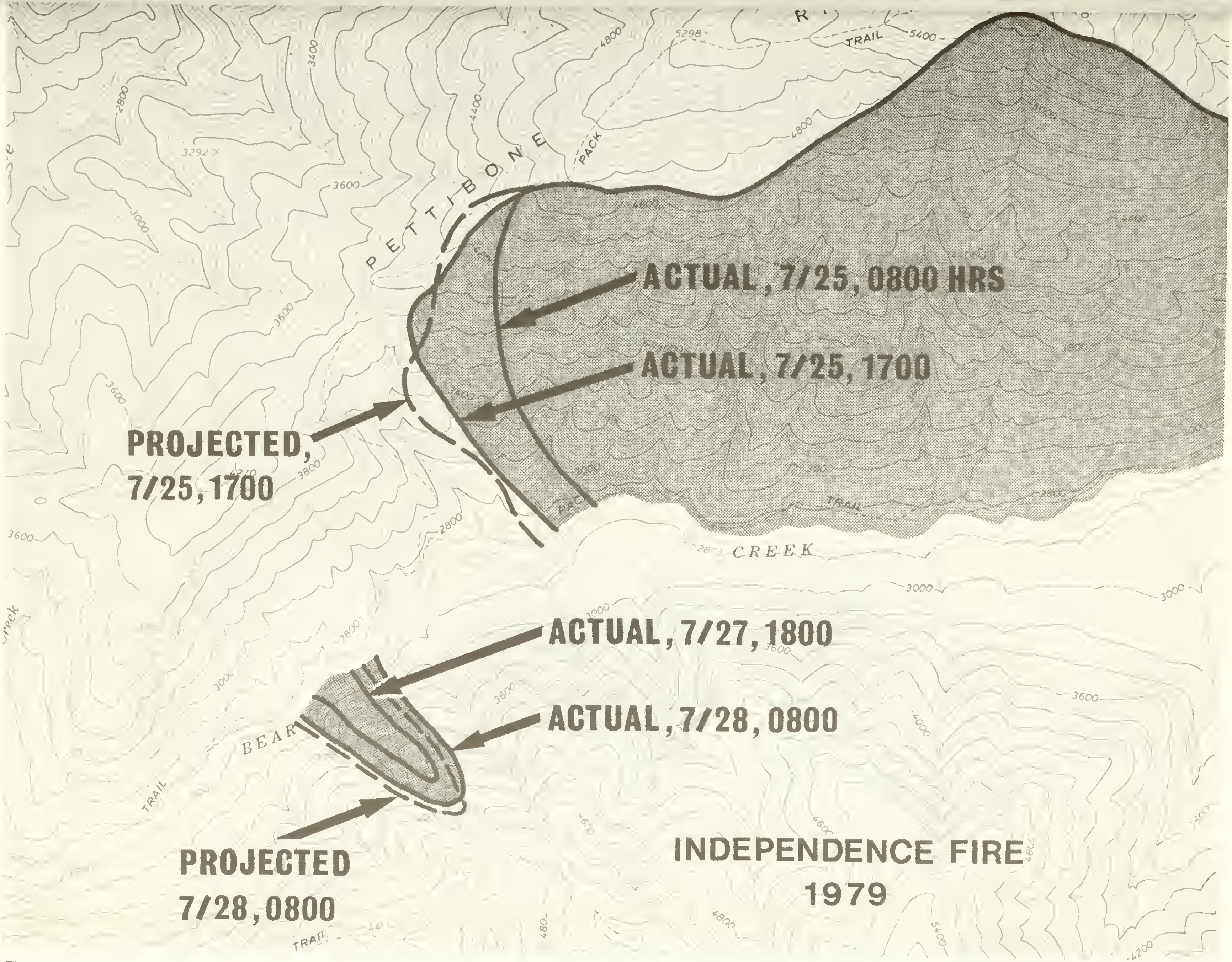


*Figure 21.—Examples of actual fire perimeter locations compared to the projected locations made by Larry Keown, Fire Management Officer, on the 1979 Independence Fire in the Idaho Selway-Bitterroot Wilderness.*

## SUMMARY


This paper shows how a person skilled in predicting fire behavior can verify and improve fire predictions. Four situations for verification are described:

1. Verification with forecasted weather.
2. Verification with weather measured at the time fire spread begins.
3. Verification with weather and other data observed during the fire.
4. Verification with all variables measured.

Possibilities for testing on wildfires, planned and unplanned prescribed fires, and test or experimental fires are discussed.

The most detailed data collection can be made only on easily accessible fires. A data sheet format and procedures for collecting data are given in detail. Analysis procedures indicate how to compare predicted and observed data and how to improve predictions. On severe fires or fires that are inaccessible, data will usually not be complete. In these cases the most important thing to determine is the fire position versus time. This can then be compared to predicted position made with either forecasted weather or observed weather.


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# APPENDIX

## The Two-Fuel-Model Concept

If nonuniformity of the fuel makes it impossible to select a single representative fuel model, then the two-fuel-model concept should be applied.

The two-fuel-model concept is designed to account for changes in fuels in the horizontal direction, i.e., as the fire spreads, it will encounter significantly different fuels. It is not designed to account for variability in the vertical direction, i.e., growth from one stratum to the next on the same spot is not modeled. It is still necessary to identify the stratum that will carry the fire.

The concept is very simple. It assumes horizontally nonuniform fuels can be described by two fuel models, in which one represents the dominant vegetative cover over the area and the second represents fuel concentrations that interrupt the first. For example, in a forest stand the dominant fuel stratum over most of the area may be short needle litter (fuel model 8) with concentrations of dead and down limbwood and treetops. Depending on the nature of these jackpots, they could be described by model 10 or one of the slash models, 12 or 13. An important feature of the concept is that it is not necessary to try to integrate the effect of both the needle litter and limbwood accumulation into one model. Two distinct choices can be made.

Another example is rangeland, where grass may be the dominant vegetation over the area, with brush concentrations interspersed within the grass. Of course the system will work vice versa, where brush is dominant with interruptions caused by concentrations of grass.

The additional requirements for using the two-fuel-model concept is that it is necessary to make an estimate of the percent cover of the two fuels.

The concept is implemented in a six-step process:

1. Select a fuel model that represents the dominant cover, i.e., 50 percent or more of the area.
2. Select a fuel model that represents fuel concentrations within the dominant cover.
3. Estimate the percentage cover of the two fuels. The sum of the two must equal 100 percent.
4. Using fire behavior models for uniform fuels, calculate rate of spread and fireline intensity in each fuel separately. Select the most appropriate midflame windspeed and use the same value in the rate of spread and fireline intensity calculations.
5. Calculate the most probable rate of spread as the sum of the two spread rates weighted by the percent cover of the two fuels.

Example: Fuel model A covers 75% with R = 10 ch/h
Fuel model B covers 25% with R = 80 ch/h
Most probable $R = 0.75 \times 10 + 0.25 \times 80$
$= 7.5 + 20$
$= 27.5$ ch/h

6. Do not try to combine fireline intensities. As a first approximation, simply estimate that the intensity values calculated separately will occur with the same frequency as the estimated cover fraction of each fuel model.

This can provide important information about the character of the fire. In the case of the needle litter and limbwood jackpots beneath a timber stand: if the litter covered 80 percent of the area with an expected fireline intensity of 75 and the limbwood and treetop accumulation occupied the remaining 20 percent with an expected fireline intensity of 800, then the overstory should be examined for its potential for crowning and producing firebrands. Fire control personnel should be aware that fire in the litter could probably be controlled by hand crews, but the jackpots could cause severe problems.

Utilizing two fuel models to characterize an area greatly increases the flexibility of the 13 stylized fuel models to match conditions in the field. It does require that the fuel and fire behavior specialist become more adept at identifying fuels and that more attention be paid to the interpretation of the variable nature of fire behavior.

Rothermel, Richard C.; Rinehart, George C. Field procedures for verification and adjustment of fire behavior predictions. Gen. Tech. Rep. INT-142. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 25 p.

The problem of verifying predictions of fire behavior, primarily rate of spread, is discussed in terms of the fire situation for which predictions are made, and the type of fire where data are to be collected. Procedures for collecting data and performing analysis are presented for both readily accessible fires where data should be complete, and for inaccessible fires where data are likely to be incomplete. The material is prepared for use by field units, with no requirements for special equipment or computers. Procedures for selecting the most representative fuel model, for overall evaluation of prediction capability, and for developing calibration coefficients to improve future predictions are presented. Illustrated examples from several fires are included. The material is a companion publication to the fire prediction manual titled, "How to predict the spread and intensity of forest and range fire," by R. C. Rothermel.

KEYWORDS: fire prediction verification, rate of spread, flame length

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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