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Abstract

Information is presented on establishment, survival, and growth of seven selected browse species in a ponderosa pine forest over a 10-year period. Methods of establishment included hand seeding and planting bare-root and containerized stock. Success of different methods differed with shrub species.

Acknowledgment

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MANAGEMENT IMPLICATIONS

The results of this study indicate that shrub species can be successfully reestablished on both old-burn and open-pine sites in the Black Hills. For best success, the choice of shrub species should be coupled with the most suitable planting technique. Competition from native grasses and forbs should be reduced. Observations indicate that the key to revegetation of game ranges in the Black Hills by shrub planting may be the fortuitous occurrence of several years having 18 inches of precipitation or more, providing continuous moisture during the critical stage of root establishment and development.

Silver buffaloberry and silverberry grew to large size on both burned and unburned areas. Saskatoon serviceberry grew moderately well on the unburned area, and common chokecherry growth was fair on both areas. Silverberry was by far the most vigorous root sprouter, producing many new plants in the vicinity of the parent plant. This species would be a good choice for planting where browsing pressures are a problem because it has a lower palatability for deer and cattle. It provides good cover for large and small game, buds and berries for birds, and emergency food for deer during critical winter periods.

Common chokecherry and saskatoon serviceberry are questionable for planting because of exacting site requirements for good growth. Both of these species are rootsprouters and will spread when site conditions permit.

Antelope bitterbrush and mountainmahogany were the only seeded species studied that offer much promise for revegetating game ranges. Mountainmahogany has a very restricted range in the Black Hills, and no antelope bitterbrush was found in the area. However, the limited success of seeding antelope bitterbrush in this study would tend to recommend it for browse habitat improvement in the Black Hills. When costs are not a major consideration and full stock is desired, the use of bare-root stock is much more effective. With this method, moisture conditions must be proper to permit root elongation and enhance survival.

It must be remembered that good seed years combined with several years of good precipitation are rare. These conditions, coupled with low populations of rodents and large herbivores and, in addition (but very important), the presence of disturbed sites where growing space is available, happen infrequently. Therefore, one should expect more failures than successes. Nevertheless, on critically needed deer ranges where only a few remnant shrubs remain, palatable and nutritious browse species can be reestablished with techniques described in this study.

A comparison between the old-burn and the open-pine sites indicated that hand-seeded shrubs and those planted as containerized stock survived and grew better on the burn. Shrubs planted as bare-root stock survived and grew well on both sites. Containerized seedlings had a higher survival at the end of 10 years than plants established from hand seeding in the field. However, there was little difference in growth of the shrubs between planting methods. Mortality for all shrub species was highest during the first 2 years on both sites. There was little mortality for the remaining 8 years of the study.

Hand seeding mountainmahogany and antelope bitterbrush was most promising for revegetation because they had better growth and survival than other species. Establishment of common chokecherry by bare-root stock was the most effective method. Silverberry and silver buffaloberry grew best of the species established by bare-root stock.

The most successful method overall of establishing shrubs on both sites was by planting bare-root stock. Planting containerized seedlings was the next most successful (table 1). Hand seeding in the fall was least effective, but suitable for some species such as antelope bitterbrush.

Results from this 10-year study indicate that shrubs can be reestablished on depleted game ranges in the central Black Hills of South Dakota.

Table 1.—Summary of the most effective planting methods of individual shrub species and rating of species for establishment, survival, and growth on old-burn and open-pine sites

Species	Best method[1] both sites	Establishment success[2]		Survival[2]		Growth[2]	
		Burn	Pine	Burn	Pine	Burn	Pine
Antelope bitterbush	C	G	M	G	G	G	M
Silverberry	B	F	F	M	F	G	G
Common juniper	B	F	F	F	P	F	F
Common chokecherry	B	M	M	M	M	P	P
Silver buffaloberry	B	F	F	F	F	G	M
Mountainmahogany	C	M	M	M	M	F	F
Saskatoon serviceberry	B	F	F	F	F	P	P

[1] *C—Containerized stock; B—Bare-root stock.*
[2] *Rating system: G—Good; M—Moderate; F—Fair; P—Poor.*

INTRODUCTION

A major problem in managing deer in the Black Hills of South Dakota and in much of the western United States has been the loss of good deer habitat through continued deterioration of staple browse plants on old-burn winter ranges (Berner 1953, Bever 1959). Similar deterioration exists on sites occupied by ponderosa pine. Many shrub species are not able to complete successfully with grass, forbs, and pine. Native browse species sometimes have low vigor on some overbrowsed ranges even after grazing has been reduced. The shrubs are mostly old and decadent; regeneration is poor or absent. On ranges where native shrubs can no longer revegetate depleted areas, introduction of new shrubs and/or reintroduction of native species may be the best way to improve the supply of browse plants.

Although browse planting and seeding is considered expensive and impractical in the eastern states (Bartlett 1950, Latham 1950), it has been successful in many western states (Holmgren 1954; Hubbard et al. 1959; Plummer et al. 1962, 1964, 1968; White and Boyd 1957; Springfield 1972). Springfield (1972) presented data on germination and growth of game forage species in New Mexico. Plummer et al. (1962) found first-year establishment of browse species from direct seeding depends on a coincidence of good precipitation, absence of competition, and favorable temperatures in the early spring period.

Much of the work on shrub revegetation in the West has been with antelope bitterbrush (*Purshia tridentata*) (Brown and Martinsen 1959, Holmgren and Basile 1959, Hubbard 1964). Nord (1965) gives a review of the autecology of antelope bitterbrush in California. Wagle (1958) reported on a comprehensive study of early growth variation in antelope bitterbrush and its relation to the environment.

There have been only limited shrub planting trials in the Black Hills (McEwen and Hurd 1959). Berner (1953) suggested reseeding or planting browse species coupled with some method of control or reduction of deer as a means of improving deer winter range.

The objectives of this study were to determine (1) the germination success of seeding trials in the field at two sites, (2) the germination of shrubs in the greenhouse, (3) which shrub species were best suited to the environment, and (4) how to effectively establish superior shrubs on two important deer habitat types in the ponderosa pine forests of the Black Hills of South Dakota.

STUDY AREA AND METHODS

Two study sites were selected on the Black Hills National Forest. The old-burn study site, 10 miles north-northwest of Hill City in the Black HIlls of South Dakota, was near the center of the McVey burn, a large area (21,857 acres) burned by wildfire in 1939 (fig. 1). This area has become one of the most utilized deer winter ranges in the Black Hills. Native vegetation on the planting site consisted of saskatoon serviceberry (*Amelanchier alnifolia*), Woods rose (*Rosa woodsii*), little bluestem (*Andropogon scoparius*), fringed sagebrush (*Artemisia frigida*), common snowberry (*Symphoricarpos albus*), and Kentucky bluegrass (*Poa pratensis*). The open-pine site, 15 miles north-northwest of Hill City, is on the edge of the main winter deer range (fig. 2). This site has an open stand of mature ponderosa pine (*Pinus ponderosa*) with a sparse understory of bearberry (*Arctostaphylos uva-ursi*), and scattered remnants of common chokeberry (*Prunus virginiana*) and saskatoon serviceberry. Wild strawberry (*Fragaria ovalis*) and groundplum milkvetch (*Astragalus crassicarpus*) are common forbs on the area. Fire scars on the mature pines and charcoal in the soil indicate that the area burned prior to 1900.

In the Black Hills, approximately 70% of the precipitation falls during the growing season, May through September, as shown below (in inches):

Month	Old-burn site	Open-pine site
January	0.50	0.53
February	0.69	0.74
March	0.87	0.82
April	2.08	2.21
May	3.36	3.79
June	4.20	4.11
July	3.19	3.41
August	1.87	1.94
September	1.35	1.23
October	0.61	0.56
November	0.75	0.77
December	0.54	0.54

Figure 1.—The shrub planting site on the old-burn site rapidly reforested with ponderosa pine between the initiation of the study (A) and 10 years later at its termination (B).

Figure 2.—The open-pine site, typical of deer ranges in the central Black Hills, is dominated by open ponderosa pine.

Precipitation normally increases during May and reaches a maximum in June. Annual precipitation decreased each year for the three planting years. Total annual and growing season precipitation at the open-pine site exceeded that at the old-burn site as shown below (in inches):

Year	Old-burn site	Open-pine site
1	18.7	21.4
2	16.3	18.9
3	15.2	16.6
4	15.5	14.9
5	24.8	26.2
6	23.6	24.2
7	19.2	22.3
8	26.9	28.9
9	16.9	17.0
10	24.4	21.0
11	16.9	15.0
Average	19.8	20.6

Soils on both sites are of metamorphic schist parent material, top soil depths are similar (5-6 inches), and slopes are comparable (36%-39%). The sites are in the 18- to 20-inch annual precipitation zone in the Black Hills. While the sites are physiographically comparable, they represent two specific deer habitat types.

Seven-foot-high fences were built on each site to protect an area 60 by 100 feet from livestock, deer, and rabbits. The exclosures were subdivided into three plots each 33 by 60 feet. These plots were randomly assigned a year to be planted—first, second, or third. The plots were further divided into two 30- by 33-foot subplots. These subplots were randomly assigned for spring or fall planting. Nine rows, 3 feet apart and 15 feet long, were established on the contour in each subplot. Shrub species were randomly assigned to these rows.

Planting techniques were (1) hand seeding in the fall, (2) containerized seedlings planting in the spring, and (3) spring planting of bare-root stock.

Germination

The following plants were hand seeded: antelope bitterbrush, common chokecherry, comon juniper (*Juniperus communis*), pin cherry (*P. pensylvanica*), mountainmahogany (*Cercocarpus montanus*), and snowbrush ceanothus (*Ceanothus velutinus*). Seeds were collected locally the year prior to planting except for antelope bitterbrush which was collected in Idaho because it does not occur in the Black Hills. Seeds were not treated prior to sowing except that one-half of the antelope bitterbrush seeds were treated with a toxicant/repellent to discourage rodents. Seeds were sown approximately 2 inches apart and 1 inch deep in hand-cultivated rows.

The following species were seeded in the greenhouse: antelope bitterbrush, common chokecherry, common juniper, pin cherry, mountainmahogany, and snowbrush ceanothus. All seeds and fruits were stratified from 39 to 99 days in moist vermiculite at 45° F. Common chokecherry seeds were scarified to break dormancy. In addition, snowbrush ceanothus seeds were soaked in boiling water and 3% thiourea solution to break dormancy. Three to five stratified seeds were planted in a mixture of three parts soil to one part washed river sand in a tarpaper pot. Germination was recorded biweekly during the early growing season both in the field and in the greenhouse.

Establishment of Shrubs

The following containerized species were planted in the spring: antelope bitterbrush, common chokecherry, common juniper, pin cherry, mountainmahogany, and snowbrush ceanothus (fig. 3). Seedlings were hardened in cold frames for 1 month prior to field planting in early May.

Bare-root nursery stock of common chokecherry, saskatoon serviceberry, silverberry (*Elaeagnus commutata*), silver buffaloberry (*Shepherdia argentea*), and common juniper were obtained from commercial nurseries and planted during the latter part of April. A trench 6 inches deep was excavated along the contour of the slope in which shrubs were equally spaced at 18-inch intervals. All shrubs were watered at the time of planting.

The bare-root stock ranged in height from 6 to 9 inches for saskatoon serviceberry and 18 to 24 inches for silverberry. Common chokecherry, saskatoon serviceberry, and silver buffaloberry were top-pruned approximately one-third at the time of planting. The rows were cultivated by hand during the summer of each year.

Figure 3.—Shown are the size and shape of tar-paper containers used for growing antelope bitterbrush seedlings in the greenhouse (A) and comparative size of potted seedlings (B) at time of field transplanting (from left to right): antelope bitterbrush, common chokecherry, pin cherry, mountainmahogany, and silverberry (1-inch squares).

Survival of the plants was recorded biweekly for eight growing seasons, and a final measurement was made 10 years after planting. Overwinter survival and total plant height was recorded during the first week of May and September of each year.

RESULTS

Germination of Shrubs

A factorial analysis of variance was used to compare the germination success of mountainmahogany, common chokecherry, and treated and untreated antelope bitterbrush on the two sites for 3 years on two replicated rows. There were differences among sites ($p \leq 0.01$), years ($p \leq 0.05$), and species ($p \leq 0.10$). There was a significant ($p \leq 0.05$) interaction between site and years, but no differences between replications. The toxicant/repellent-treated antelope bitterbrush seeds generally had a germination success averaging 5%-10% higher at the burn and pine sites, respectively (table 2).

Antelope bitterbrush germination was higher than either mountainmahogany or common chokecherry at both locations, while the latter two species showed about equal germination. Many of the fall seeded species including common juniper, pin cherry, and snowbrush ceanothus, had little or no germination on either site, indicating the need for either preseeding treatment or more favorable planting conditions.

Germination in the greenhouse varied considerably among species. Antelope bitterbrush seeds germinated best with an overall average of 49% (table 3). The success of other shrubs in germinating ranked as follows: mountainmahogany > common chokecherry > snowbrush ceanothus > pin cherry. Common juniper seeds and fruits could not be germinated.

Establishment of Shrubs

Fall Seeding

Fall seeding at the burn site showed that survival after the first growing season decreased for antelope bitterbrush, mountainmahogany, and common chokecherry (table 4). After 10 years, antelope bitterbrush exhibited the highest survival rate (22%). Mountainmahogany had the least number of plants surviving after 10 years (4%). Common chokecherry showed the greatest loss in survival, decreasing from 42% the first year to 6% the tenth year.

On the open-pine site, survival of the three shrub species from fall seeding decreased after the first growing season to the tenth growing season (table 4). Antelope bitterbrush had the highest survival after 10 years with 8%. During the tenth growing season, mountainmahogany and common chokecherry had survival rates of approximately 3%.

Antelope bitterbrush seeded on the old-burn site had a higher survival at the end of the study than either

Table 2.—Germination of shrub seeds planted in the fall of 3 consecutive years on old-burn and open-pine sites

Species	Seeds planted	Percent germination			
		Year 1	Year 2	Year 3	Average
		percent			
Old-burn site					
Antelope bitterbrush[1]	180	28	31	[2] 24	27
Antelope bitterbrush	180	33	26	[2] 14	22
Common chokecherry	360	13	12	31	19
Mountainmahogany	360	38	6	14	19
Open-pine site					
Antelope bitterbrush[1]	180	46	44	[2] 32	39
Antelope bitterbrush	180	36	37	[2] 22	29
Common chokecherry	360	29	[3] 30	26	28
Mountainmahogany	360	38	15	24	26

[1] *Toxicant/repellent treated.*
[2] *Seeds planted—360.*
[3] *Seeds planted—180.*

Table 3.—Greenhouse germination of seeds of selected shrub species for 3 consecutive years

Species	Year 1		Year 2		Year 3		Average
	Planted	Emerged	Planted	Emerged	Planted	Emerged	
	number	*percent*	*number*	*percent*	*number*	*percent*	*percent*
Antelope bitterbush	1,100	48	400	34	1,440	54	49
Mountainmahogany	1,175	17	1,000	33	1,162	24	24
Common chokecherry	810	3	100	11	1,152	33	20
Snowbrush ceanothus	540	28	1,000	1	0	0	10
Pin cherry	640	0	400	3	612	3	2
Common juniper	850	0	300	0	216	0	0

Table 4.—Average survival of fall seeded shrub species (percent plus or minus standard error) over a 10-year period on old-burn and open-pine sites in the Black Hills of South Dakota

Species	Growing season[1]			
	First	Second	Fifth	Tenth[2]
Old-burn site				
Antelope bitterbush	51.7 ± 9.5	40.6 ± 9.7	23.9 ± 4.0	21.8 ± 5.0
Mountainmahogany	23.5 ± 6.4	15.4 ± 4.9	4.2 ± 2.4	4.2 ± 2.4
Common chokecherry	41.8 ± 7	25.9 ± 9.5	7.6 ± 7.6	6.3 ± 6.3
Open-pine site				
Antelope bitterbush	40.4 ± 7.5	19.0 ± 5.8	8.3 ± 4.2	8.3 ± 4.2
Mountainmahogany	27.8 ± 1.0	14.0 ± 2.6	10.1 ± 4.6	3.6 ± 1.9
Common chokecherry	32.2 ± 10.4	20.8 ± 15.3	7.0 ± 7.0	3.2 ± 3.1

[1]*Sample size n = 3 consecutive years; number of seeds planted each year by species ranged from 180-360.*
[2]*Final survival measurements represent an average of the ninth through eleventh years.*

antelope bitterbrush seeded at the open-pine site or common chokecherry and mountainmahogany seeded at either location. Mountainmahogany and common chokecherry survived poorly at both sites.

Growth of antelope bitterbrush established from fall seeding was superior to growth of mountainmahogany and common chokecherry on both old-burn and open-pine sites for the first 5 years (fig. 4). After 10 years, antelope bitterbrush and mountainmahogany were comparable and exceeded common chokecherry in height on both study areas. Furthermore, antelope bitterbrush and mountainmahogany had higher growth rates on the old-burn site than on the open-pine site, and after 5 years were almost twice as tall as common chokecherry. After 10 years, all three shrubs on the old-burn site were about one-third taller than those on the open-pine study area. Even though common chokecherry grew taller on the old-burn area than on the open-pine area, both sites were still producing only small plants after 10 years.

Containerized Seedlings

Antelope bitterbrush and mountainmahogany plants grown in the greenhouse and transplanted to the field had a higher survival than common chokecherry seedlings established in the same manner (table 5). There was no survival of common chokecherry plants at the end of the fifth growing season. Antelope bitterbrush survived better on the old-burn site after 10 years, with a 20% survival rate; on the open-pine site, 11% survived. Mountainmahogany during the tenth year had survival rates of 18% and 7% on the open-pine and old-burn sites, respectively.

The growth rates were higher for antelope bitterbrush on both the old-burn and open-pine sites during the first 5- to 7-year period after plants were established when compared to mountainmahogany (fig. 5). By the tenth year, mountainmahogany was much taller than antelope bitterbrush (figs. 6 and 7).

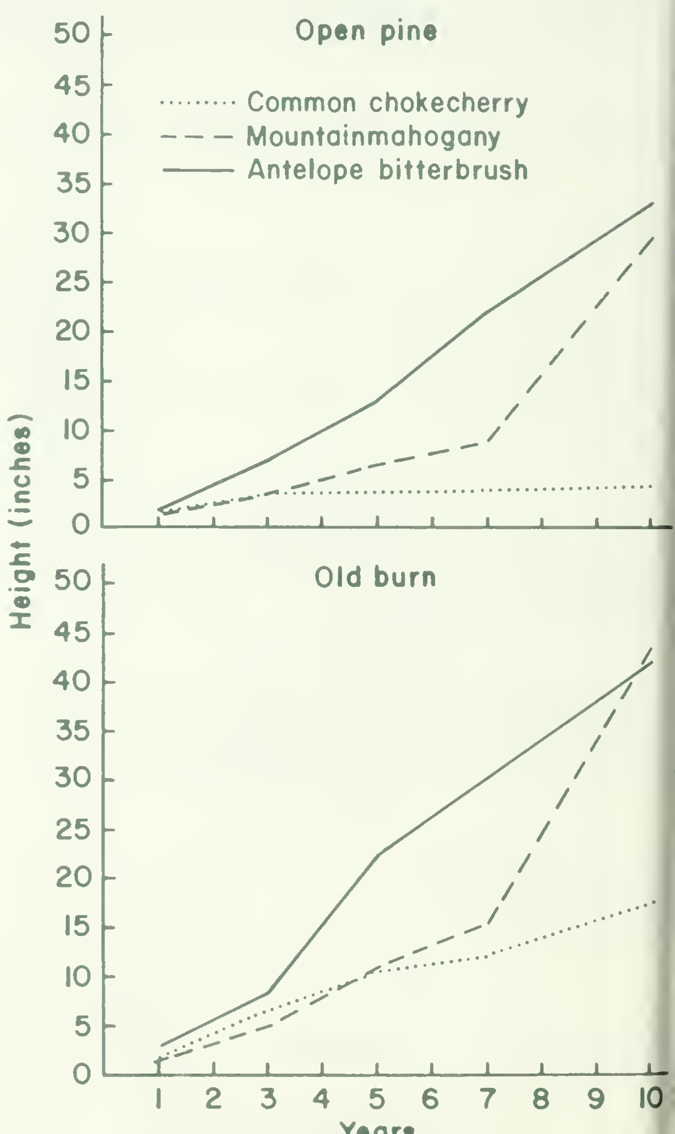

Figure 4.—Comparative growth curves shown for antelope bitterbrush, mountainmahogany, and common chokecherry established by fall seeding at the old-burn and open-pine sites for the first seven growing seasons and at the end of the tenth growing season.

Table 5.—Average survival of containerized planting stock of shrubs (percent plus or minus standard error) over a 10-year period on old-burn and open-pine sites in the Black Hills of South Dakota

Species	Growing season[1] First	Second	Fifth	Tenth[2]
Old-burn site				
Antelope bitterbush	66.5 ± 14.9	36.4 ± 8.6	26.9 ± 8.3	20.2 ± 8.7
Mountainmahogany	62.4 ± 15.1	22.5 ± 2.7	7.4 ± 2.2	6.7 ± 2.5
Common chokecherry	21.4 ± 10.7	8.1 ± 8.1	0.0 ± 0.0	0.0 ± 0.0
Open-pine site				
Antelope bitterbush	56.9 ± 12.5	26.1 ± 4.6	14.2 ± 3.7	11.0 ± 4.1
Mountainmahogany	71.5 ± 10.4	37.1 ± 15.8	18.2 ± 7.5	18.2 ± 7.5
Common chokecherry	17.8 ± 9.7	4.5 ± 4.5	0.0 ± 0.0	0.0 ± 0.0

[1] *Sample size n = 3 consecutive years.*
[2] *Final survival measurements represent an average of the ninth through eleventh years.*

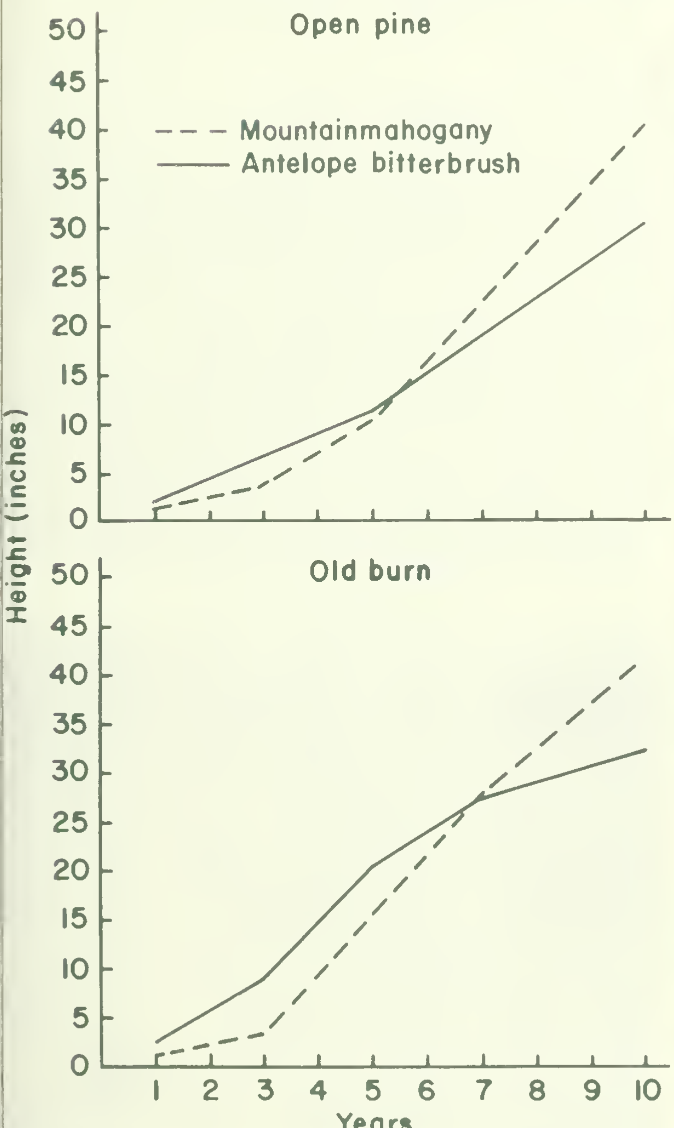

Figure 5.—Comparative growth curves are shown for antelope bitterbrush and mountainmahogany established by containerized seedlings at the old-burn and open-pine sites for the first seven growing seasons and at the end of the tenth growing season.

Figure 6.—Antelope bitterbrush grew rapidly and developed into large productive bushes in 10 years on the old-burn site (A), and performed nearly as well at the open-pine site (B). Grid interval in A is 1 foot.

Table 6.—Average survival of bare-root planting stock of shrubs (percent plus or minus standard error) over a 10-year period on old-burn and open-pine sites in the Black Hills of South Dakota

Species	Growing season[1]			
	First	Second	Fifth	Tenth[2]
Old-burn site				
Common chokecherry	80.4 ± 3.7	73.5 ± 7.1	47.7 ± 9.6	27.6 ± 9.9
Saskatoon serviceberry	69.1 ± 22.6	39.1 ± 9.5	3.7 ± 2.3	0.0 ± 0.0
Silverberry	57.8 ± 21.6	43.8 ± 22.3	35.8 ± 17.9	30.5 ± 15.4
Silver buffaloberry[2]	50.0	43.3	30.0	30.0
Common juniper	28.9 ± 14.9	15.5 ± 8.0	12.2 ± 6.2	12.2 ± 6.2
Open-pine site				
Common chokecherry	68.6 ± 13.9	46.2 ± 8.4	57.5 ± 12.5[3]	37.1 ± 11.9
Saskatoon serviceberry	91.7 ± 5.2	44.6 ± 24.6	40.9 ± 24.5	31.3 ± 21.3
Silverberry	50.0 ± 28.9	38.0 ± 22.1	32.2 ± 18.3	15.8 ± 8.1
Silver buffaloberry[2]	100.0	100.0	90.0	63.3
Common juniper	43.3 ± 22.7	22.2 ± 11.3	10.0 ± 6.9	6.6 ± 3.8

[1]*Sample size n = 3 consecutive years of plantings.*
[2]*n = 1 year.*
[3]*Increased percentage due to resprouting from original rootstocks.*
[4]*Final survival measurements represent an average of the ninth through eleventh years.*

Bare-Root Stock

Survival of bare-root stock for common chokecherry at both sites was higher during the first and second year than for plants started by fall seeding or containerized seedlings (table 6). With a few exceptions, saskatoon serviceberry transplants survived well the first year in the field, but many died the second year and, by the end of the tenth growing season, no live plants remained. Silverberry transplants generally had a higher survival during their first year in the field than silver buffaloberry and common juniper.

At the old-burn site, the survival of common chokecherry and silverberry bare-root transplants was higher than other species at the end of the tenth growing season. On the open-pine site, 37% of common chokecherry survived after 10 years, while survival of saskatoon serviceberry and silverberry were 31% and 16%, respectively. The highest survival occurred with silver buffaloberry with 63% at the end of the tenth season. Planting nursery stock was the only successful means for establishing common juniper.

On both areas, common chokecherry and saskatoon serviceberry established from bare-root transplants had poor growth rates, but each were taller on the old-burn site after 5 years (figs. 8 and 9). Saskatoon serviceberry had completely died out by the tenth year on the old-burn site, but tripled in growth from the fifth to the tenth year on the open-pine site (fig. 8). Silverberry was superior to both common chokecherry and saska-

Figure 7.—Mountainmahogany plants established 10 years previously from potted seedlings have survived well on both the old-burn (A) and open-pine (B) sites.

toon serviceberry in growth. The silverberry plants grew taller on the old-burn study area than at the open-pine site (fig. 10). This same trend was observed with silver buffaloberry (fig. 11).

DISCUSSION

Germination of Shrubs

Common chokecherry, snowbrush ceanothus, and mountainmahogany varied widely in germination success in the greenhouse and in the field during the 3 years of planting. Germination of antelope bitterbrush seeds in the greenhouse was higher than that obtained at both the open-pine and old-burn sites. Common chokecherry germination was higher in the field than in the greenhouse. Mountainmahogany germination was highest at the open-pine site and lowest on the old-burn site.

The effects of treating seeds to break dormancy varied with species. Scarification improved germination slightly for common chokecherry. The thiourea treatment increased the emergence of snowbrush ceanothus.

Better seedling emergence of most species on the open-pine site may have been caused by more favorable soil moisture conditions resulting from higher fall precipitation at that site combined with partial shading provided by the pine overstory. For antelope bitterbrush, Nord (1965) states that during late fall, winter, and early spring, the soil must be moist at least to the depth of the planted seed.

Factors affecting germination success in the greenhouse were more related to method of seeding

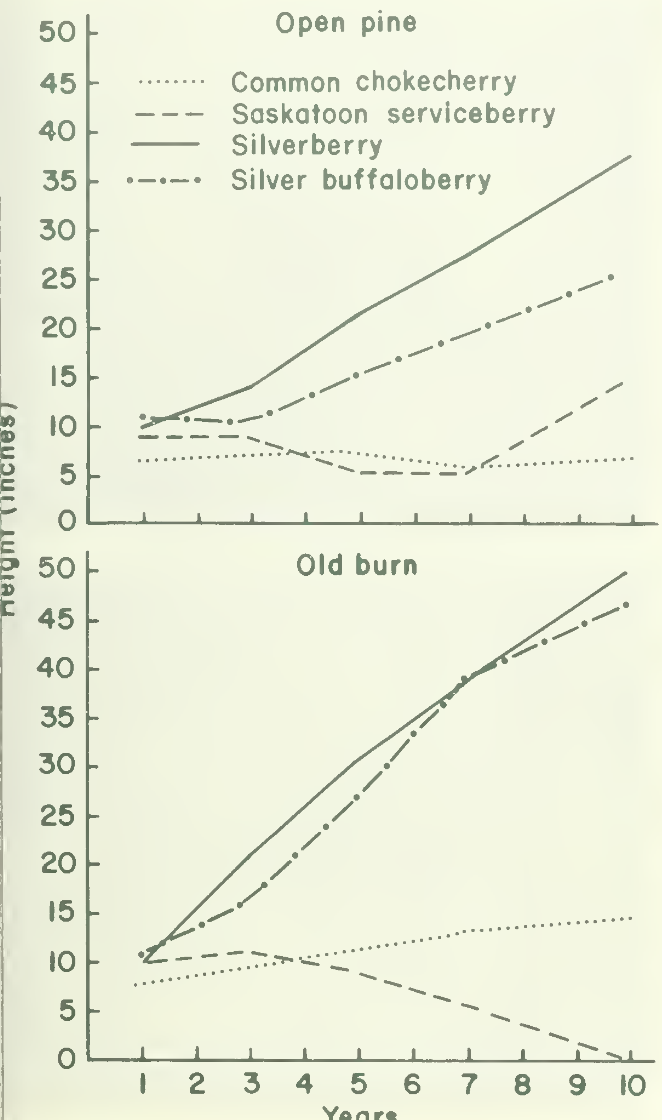

Figure 8.—Comparative growth curves for bare-root stock of four shrub species during the first seven growing seasons and at the end of the tenth growing season.

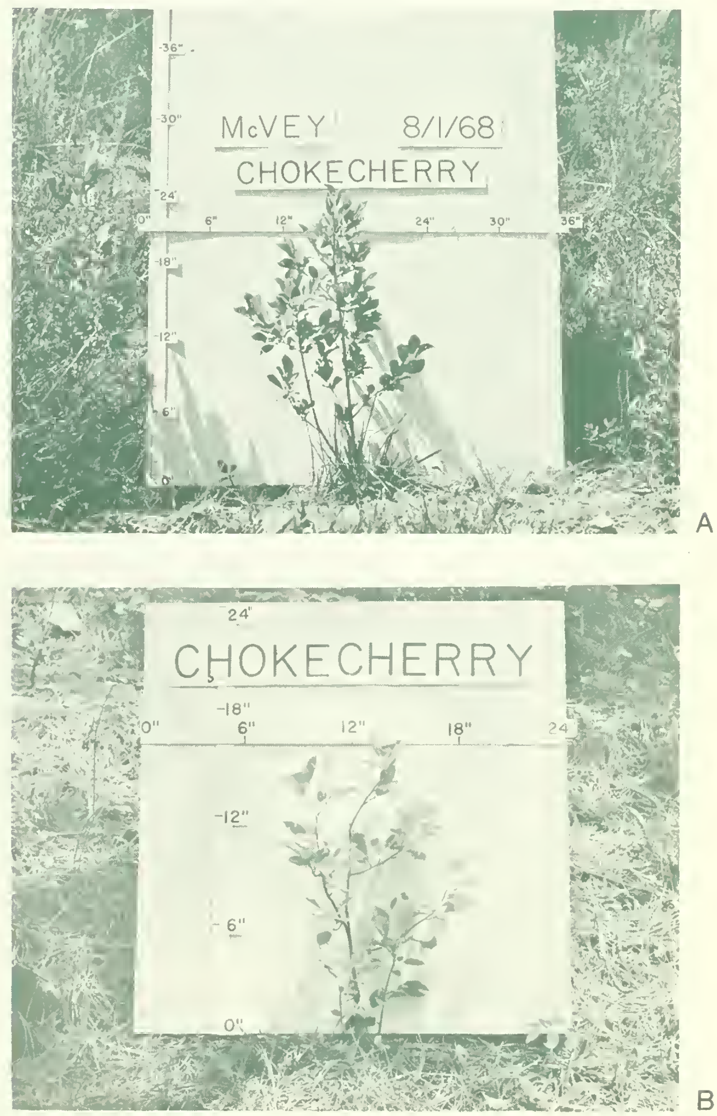

Figure 9.—Common chokecherry, although surviving well on both the old-burn (A) and open-pine (B) sites, has remained small because of winter dieback.

treatment to break dormancy than other factors. Adequate soil moisture conditions were maintained at all times. The wide variability in germination results obtained with scarification, boiling, and thiourea treatment indicates a need for additional studies to develop techniques for breaking seed dormancy.

Factors Affecting Browse Establishment

Comparisons of browse establishment between the old-burn and open-pine locations indicated the burn area was more suitable for shrub revegetation. A major reason for this is that the old-pine site was not disturbed (i.e., fire, although competing herbaceous vegetation was partially controlled by cultivation on both sites). Competition with pine alone is a major factor influencing the difference in survival at the two locations. Higher mortality of planted browse species the first 2 years and their subsequent lower survival the remaining 8 years on the open-pine area probably was due to competition for soil moisture and sunlight. Consequently, survival was generally higher at the old-burn site.

The growth trend of the browse plants coincided closely with the survival trend. Containerized stock of most species were more hardy than plants established from hand planting of seeds during the first, and in some instances, during the second growing season because of more extensive root development and partial protection provided by the planting container. The plants on the old-burn site were generally several inches taller than those growing on the open-pine site. Average heights generally increased each growing season, except for a few species such as common chokecherry where average heights decreased during

A

B

Figure 10.—Silverberry plants established from containerized stock have shown excellent growth on the old-burn (A) and good growth at the open-pine site (B). Profuse root sprouting occurred on both sites.

Figure 11.—Silver buffaloberry nursery stock grew well, especially on the old-burn site (A) and to a lesser extent at the open-pine site (B).

ome years because of winter dieback. Common chokeherry and saskatoon serviceberry showed this haracteristic more than other species. Antelope biterbrush had the greatest average height and height inrease of all species whether started from hand eeding or containerized seedlings during the first 5 ears, indicating its suitability for the Black Hills. owever, by the tenth year, mountainmahogany was ightly taller than antelope bitterbrush but had much ss total foliage. Silverberry and silver buffaloberry are-root stock grew considerably taller than either ommon chokecherry or saskatoon serviceberry and qual to or better than antelope bitterbrush and mouninmahogany indicating a good tolerance for the two reas.

The effect of drought on seedling growth and surval was difficult to determine. Some shrub mortality as definitely drought caused. For instance in the first ear of the study, 71% of the mountainmahogany seedng mortality occurred during a drought period in lay. However, only 20%-51% of total mortality of the her species occurred during the same period. Seedng mortality was greater on the old-burn site than the en-pine site during this same period.

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Information is presented on establishment, survival, and growth of seven selected browse species in a ponderosa pine forest over a 10-year period. Methods of establishment included hand seeding and planting bare-root and containerized stock. Success of different methods differed with shrub species.

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Rocky Mountain Forest and Range Experiment Station

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Chimney Spring Forest Fire History

John H. Dieterich

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Range Experiment Station
Forest Service
U.S. Department of Agriculture

USDA Forest Service
Research Paper RM-220

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Chimney Spring Forest Fire History

John H. Dieterich, Research Forester
Rocky Mountain Forest and Range Experiment Station[1]

Abstract

Analysis of data from seven specimens revealed a composite fire interval in ponderosa pine of 2.4 years from 1745 to 1876 (122 years), a shorter interval than previously reported. In all cases, composite fire intervals were shorter than individual specimen intervals.

[1]Headquarters is at Fort Collins, in cooperation with Colorado State University. Author is at the Station's Research Work Unit at Tempe, in cooperation with Arizona State University.

Chimney Spring Forest Fire History

John H. Dieterich

Management Implications

Information on historical fire frequencies in the Chimney pring area indicates that fires were common in the onderosa pine forests of northern Arizona prior to 1876. or the period studied, individual tree average fire intervals anged from 4.4 to 17 years. The composite fire interval CFI) for the entire 336-year period, 1540-1876, represented y one or more specimens averaged 4.9 years. If the CFI is omputed for the 122-year period (1754-1876) when two or nore specimens were used, the average interval was 2.4 ears. For various other selected time-spans, even shorter FI's were identified. This knowledge provides a sound asis for continuing the prescribed burning interval esearch started near Chimney Spring in 1975. Results of nis study will provide the land manager with additional nowledge needed to use fire safely and effectively in the rotection and management of natural resources.

The Chimney Spring fire history study demonstrates the importance of developing a CFI in ponderosa pine to determine more precisely the frequency of past fires for a particular location. Two factors can improve on the accuracy and utility of the CFI: (1) using as many fire-scarred specimens as possible from a small area, and (2) utilizing full stump cross sections rather than portions of sections so that the maximum possible number of fire scars can be included in the analysis.

A CFI, such as the one developed for the Chimney Spring area, is not a prerequisite for intelligent application of land-management practices. However, information on historical fire frequency and modern fire occurrence patterns can reinforce the manager's appreciation of the fact that wildfires of today bear little resemblance to those occurring during centuries past, and that intelligent use of prescribed fire will not destroy the timber stand that the manager is trying to protect.

Introduction

Recognition of the importance of fire as a natural agent of hange in various ecosystems has brought about a orresponding interest in frequency, character, and impact f historical fires. A more complete knowledge of historical res can aid in understanding the role of fire as a process in ne development of valid ecosystem theories. This nderstanding will, in turn, permit effective implementation f prescribed natural fire programs, realistic planning in nplementing new fire management policies, and preser-ation of valuable historical fire data having a consider-ble amount of public appeal and interest.

Knowledge of local fire history provides a better nderstanding of existing stand structure and helps in the terpretation of changes in age-class distribution, fuel ccumulation, understory plant communities, natural egeneration, and nutrient cycling. When used for specific tes, fire history data can be used to help provide a cientific basis for using prescribed fire at various intervals. ata from the current study will be applied to the Chimney pring Prescribed Burning Interval Study,[2] established in 1975 on a 90-acre (36-ha) tract of virgin ponderosa pine on the Fort Valley Experimental Forest near Flagstaff, Ariz. Site-specific fire history data for the Chimney Spring study area were unavailable. However, an earlier analysis of three fire-scarred stump cross sections taken from widely scattered locations on the Coconino National Forest yielded average fire intervals of 7, 12, and 12 years.[3]

This paper describes the frequency of fire on a relatively small area of ponderosa pine (*Pinus ponderosa* Laws.) on the Coconino National Forest in northern Arizona, suggests possible reasons for fire occurrence, and speculates on the characteristics of the ecosystem that existed around the turn of the century.

Literature Review

In early reports, Plummer (1912), Munger (1917), Boyce (1921), and Craighead (1927) discussed various aspects of fire history, fire ecology, climatic response, and fire damage as reflected in tree rings. Show and Kotok (1924) described fire frequency in the California pine region, concluding that fire had been an important ecological factor for centuries and that the fire interval averaged about 8 years for all areas

[2]Study Plan 75.1.5 on file. Fuels Management Research Project, orestry Sciences Laboratory, Tempe, Ariz. Sackett, Stephen S., and ohn H. Dieterich. 1976. Prescribed burning interval study for ontinued hazard reduction in all-age ponderosa pine stands.

[3]Unpublished data. Fuels Management Research Project, Forestry Sciences Laboratory, Tempe, Ariz.

studied. Their work also included observations on the formation of fire scars and the susceptibility of various tree species to fire scarring. Kotok (1933) described a study of fire incidence and damage in the mixed conifer type (of which ponderosa pine was a component) on the Stanislaus National Forest. On the basis of tree ring records, he identified 221 distinct fires that moved through the 74-acre study area between the years 1454 and 1912, leaving scars on 18% of the trees. Details of species composition of sampled trees and methods of cross-dating and verification were not included.

Lemon (1937) found a fire interval of 31 years on a single, old-growth ponderosa pine in the Black Hills of South Dakota. Keen (1937, 1940) studied ponderosa pine longevity and climatic cycles in eastern Oregon as evidenced by tree-ring records and identified average fire intervals for individual trees of 16 to 18 years.

Weaver (1943) recognized fire as an important ecological and silvicultural factor in the ponderosa pine region of the Pacific Slope and recommended intensive research that would permit more effective use of prescribed fire as a silvicultural tool and in the protection and management of the ponderosa pine type. In 1951, Weaver described fire history on the Whiteriver and San Carlos Apache Indian Reservations using cross sections from four widely scattered fire-scarred stumps. Average fire intervals ranged from 4.8 to 6.9 years. He described a fire-scarred ponderosa pine collected from the Kaibab National Forest north of Grand Canyon National Park that had 19 fire scars from a 226-year period for an average interval of 11.9 years.

Subsequently, Weaver (1955, 1959, 1961) sampled fire-scarred stump cross sections from ponderosa pine found on Colville, Warm Springs, and Yakima Indian Reservations and identified average fire intervals ranging from 8 years (Colville) to 47 years (Warm Springs). However, most of the intervals averaged between 4.8 and 11 years. Weaver (1974) summarized most of this work in a chapter entitled "Effects of Fire on Temperate Forests: Western United States." He concluded that historical fires have burned "as frequently as fuel accumulated in sufficient quantity to support combustion over the forest floor, whenever weather conditions were favorable and whenever lightning strikes or Indians cause them to start."

Soeriaatmadja (1966) expanded on the work done by Weaver on the Warm Springs Indian Reservation. He inspected freshly cut ponderosa pine stumps of fire-scarred trees from four areas that were being logged and identified average fire intervals from 14.2 to 30.2 years. The longer intervals were on the higher, more mesic sites. He recognized that the actual years of individual fires might be off by a slight amount because his work did not incorporate cross-dating and verification of exact fire years using master tree-ring chronologies. For example, he checked fire scars on an area that was known to have burned in 1938. He found 10 stumps that agreed with the 1938 date, 17 stumps that showed evidence of the fire occurring in 1939, and 8 stumps that were dated 1940. No fires had burned on the area in 1939 and 1940, indicating that, in the ponderosa pine type, reliable dating is difficult without cross-dating.

Recent studies by Arno (1976), Rowdabaugh (1978), McBride and Laven (1976), and Hall (1976) summarize fire frequency for ponderosa pine stands in four other regions of the western United States. Arno identified fire intervals of 6, 10, and 11 years on the Bitterroot National Forest in western Montana and found that fire history and forest habitat type were closely interrelated. He determined that, for all habitat types that include ponderosa pine as one of the stand components, fire frequency for the stand reflected a higher fire incidence than for any one of the individual fire-scarred trees used to determine fire frequency for the stand. (Results of the study reported on in this paper show this same relationship existing between individual tree fire histories and the composite history for the Chimney Spring area.)

Rowdabaugh (1978) reported on fire frequency in the ponderosa pine-mixed conifer forest of the Colorado Front Range. A mean fire frequency for the study area was computed to be 84 years; but for various smaller units within the larger study area, the intervals ranged from 28 to 165 years. The intervals reported in Rowdabaugh's study are longer than for ponderosa pine stands in other parts of the West. No explanation is given for this apparent anomaly.

McBride and Laven (1976) analyzed fire scars on 26 ponderosa pines collected over a wide area in the San Bernardino Mountains in southern California. They identified a fire interval of 10 years prior to 1905, when organized fire protection began, and an interval of 22 years thereafter.

Hall (1976), reporting on management implications of fire effects in the Blue Mountains of Oregon, described an average fire interval of 10 years and suggests that this 10-year average interval could be used as a guide for determining how frequently the area should be treated with prescribed fire.

Data Collection and Analysis

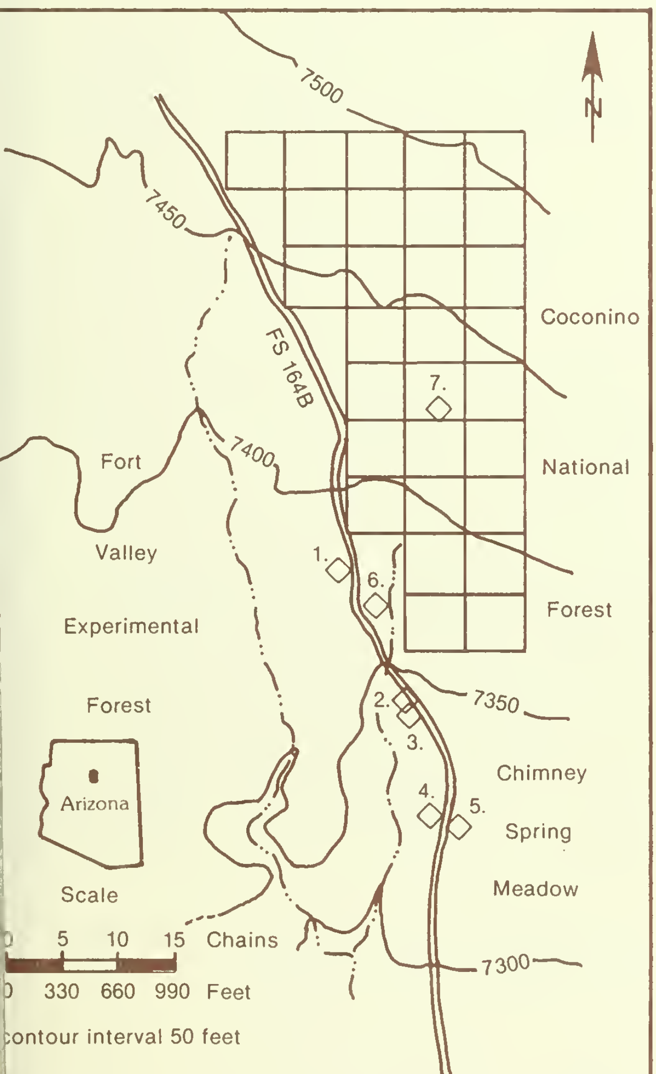
Three kinds of fire-scarred material were used to reconstruct the fire history for the Chimney Spring area: stump cross sections from freshly cut, fire-scarred trees removed in a logging operation on the adjacent area; an old stump showing well preserved fire scars; and a "half section," or wedge, from a living tree. Figure 1 shows the location of the sample trees in relation to the prescribed burning plots. The seven sample trees selected for analysis are within an area having a radius of approximately 1,200 feet (365 m). Six of the seven specimens are within an area having a radius of 660 feet (201 m).

Fire-scarred material was processed at the Laboratory of Tree-Ring Research, University of Arizona, Tucson. Cross sections were surfaced, fire scars were identified, and cross-dating and verification were completed using an established chronology for the area. In order to reconstruct a composite fire history for the stand, it was imperative that exact dates for each cross section be determined so that the composite would accurately reflect the years in which fires occurred.

An alternative to this method is a technique developed by rno and Sneck (1977) in which a master chronology was eveloped that involved the adjustment of fire-scar dates by much as 3 years. Adjustments were made based on the ct that some dates are accurate and others are pproximate or otherwise difficult to interpret.

In reconstructing a composite historical fire interval for e Chimney Spring area, some basic assumptions have een made:

1. That a fire starting within the general area where the samples were taken would have had a good chance of spreading over the entire area.
2. That a fire spreading into the area from the outside also probably would have spread over the entire area.
3. That these fires would not necessarily have burned every square foot of surface area because of fuel discontinuity, thus leaving some trees unscarred with each passing fire.



gure 1.—Fire history sample tree locations. Chimney Spring prescribed burning study site 3.5 miles northwest of Flagstaff. Individual plots are 2½ acres (1 ha) in size.

Results

Figure 2 displays the results of individual tree analyses and provides information on tree age, number and dates of fire scars, average fire intervals, date of most recent fire, and whether one or two sides of the fire scar were included in the dating process. Across the bottom of the figure is a composite of fire-years made up from dates as reflected by each individual specimen. This display makes it possible to develop a CFI for the entire period represented by the tree-ring cross sections, or for any portion of that period. Figure 2 reveals a number of facts and interesting relationships:

1. The last fire in the area was in 1876, as shown by five of seven specimens.
2. Tree 7 (536 years old) contained 31 identifiable fire scars, with the initial scar having formed in 1540 (fig. 3).
3. Complete cross sections (trees 3 and 6) revealed that fires do not always scar both sides of a "catface." Therefore, when only one side of the scarred area is used for determining fire interval, the count will be conservative.
4. Specimen 6 was a small dead stump heavily impregnated with pitch. It was impossible to determine the exact year in which the tree had been cut because the sapwood had deteriorated leaving only the pitch-impregnated heartwood and fire scars. Using a master tree-ring chronology for the area, the outside ring was dated at 1873. This tree averaged one fire every 4.4 years throughout the 88-year period, 1785-1873. Included in the total fire sequence is a 14-year period (1836-1850) where six fires scarred the tree at intervals of 3, 2, 2, 2, 3, and 2 years.
5. A gap appears in the composite fire history during the 8-year period, 1794-1802. The fire-free gap ranged from 11 years on specimen 6 to 20 years on specimen 2. This gap should not necessarily be interpreted to mean that there were no fires in the area during this period; rather, that none of the seven specimens were scarred by fires during this time span.
6. The average age of the trees when the first fire scar occurred was 121 years with a range of 63-192 years.
7. There were no instances where any of the seven specimens revealed scars in successive years. Intervals of two years were revealed on only two specimens (6 and 7).
8. There were no years when fire scars were detected on all seven specimens. The last fire recorded on the area (1876) was recorded on five of the specimens and a fire in 1785 was reflected on four of the seven specimens.

Table 1 summarizes CFI's for several different periods. Period 1 encompasses fire-scar data for all seven specimens, although fire frequency for two-thirds of this period is represented by only one specimen (7).

Period 2 provides the longest span of time (122 years) that includes data from all seven specimens. The resulting interval (2.4 years) represents a ponderosa pine fire frequency far shorter than any previously reported in the literature.

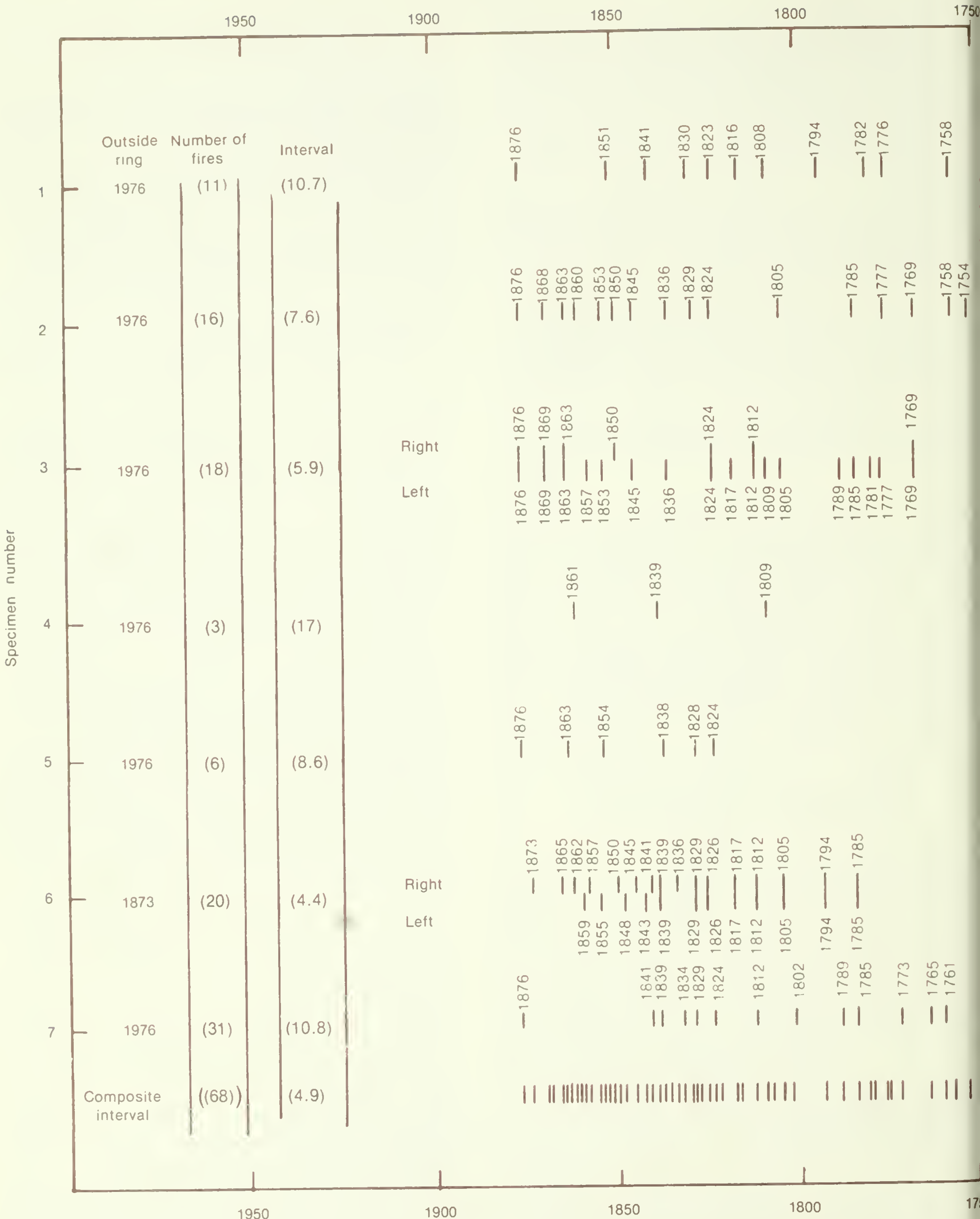
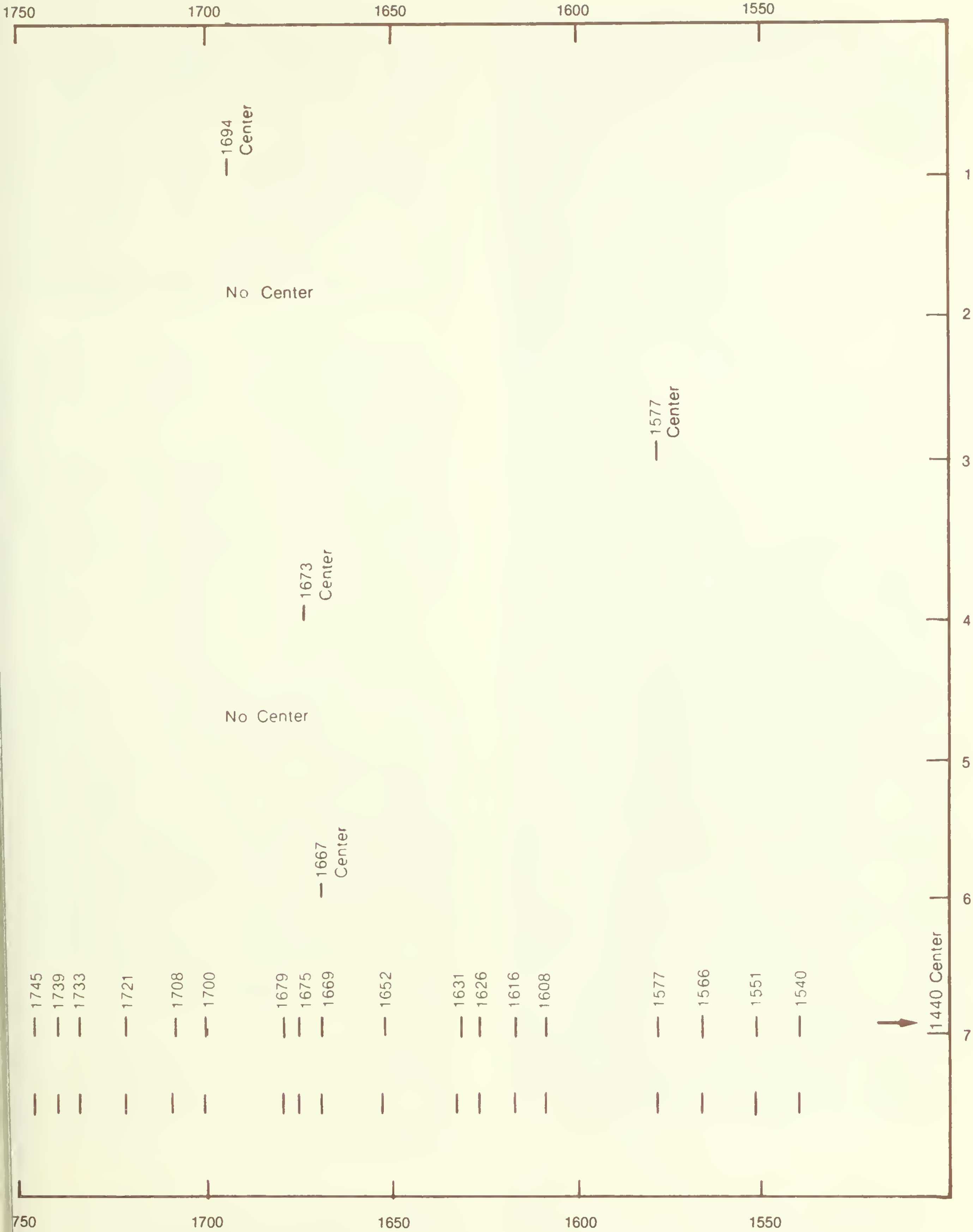


Figure 2.—Chimney Spring composite fire interval.


1750
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1631
1626
1616
1608
1577
1566
1551
1540
1440 Center
1
2
3
4
5
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7

Figure 3.—Fire scarred cross section from specimen 7, Chimney Spring plots. Thirty-one scars are identifiable between the years 1540 (first scar) and 1876 (last scar). This tree appeared to grow at a normal rate for about the first 50 years then slowed to a sustained rate of about 80 rings per inch. The section measures 11 inches (28 cm) from the outer ring (1976) to the inner ring (1440).

Table 1.—Composite fire intervals, Chimney Spring

Period	Time span[1]	Number of years	Number of recorded fires	Interval
				years
1	1540-1876	336	68	4.9
2	1754-1876	122	50	2.4
3	1800-1876	76	37	2.1
4	1820-1876	56	30	1.9
5	1824-1869	45	26	1.7
6	1850-1865	15	12	1.25

[1]*Dates between first and last fire scar. Includes all material.*

As progressively shorter periods are selected for computing fire frequency, the interval becomes even shorter. For period 6, a 15-year period (1850-1865), fires were occurring on the Chimney Spring area at 1- to 2-year intervals (average 1.25 years).

Fire-scar data from specimens 2 and 3, only 20 feet (6 m) apart, show why a single tree does not necessarily reveal the true fire interval for a particular area. Whereas tree 2 had an average interval of 7.6 years for 18 fires, and tree 3 had an interval of 5.9 years for 16 fires, the CFI is 5.3 years based on 11 fires that were common to both trees and 12 fires that affected one specimen and not the other.

Discussion

Two factors appear to be primarily responsible for the extremely short CFI's found on the Chimney Spring study site: (1) the presence of reliable ignition sources (lightning and man), and (2) the accumulation of sufficient ground fuel to permit the fires to spread once the ignitions occur.

Lightning has been a consistent cause of fires in southwestern forests for centuries. During recent times Barrows[4] reports that, in the states of Arizona and New Mexico, lightning has caused an average of 1,653 fires per year, with a fire density per unit area of 86 fires per million acres protected. The Coconino National Forest, where the study was done, experiences 327 fires per year and a fire density of 162 fires per million acres protected—the highest of the national forests in this region. In addition, the Southwest is recognized as having some of the most critical fire weather of any region in the country (Schroeder et al. 1964).

Cooper (1960) reviewed a number of historical accounts by early explorers documenting the fact that fire was used by various Southwest Indian tribes for a variety of purposes. Indians hunting and living in the San Francisco Peaks region undoubtedly contributed to fire frequency experienced in the study area.

[4]*Barrows, Jack S. 1978. Lightning fires in southwestern forests. Final report prepared by Colorado State University for Intermountain Forest and Range Experiment Station, under cooperative agreement 16-568-CA with Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo. 154 p.*

Faulk (1970) provides some insight into the possible luence of early settlement in northern Arizona on fire k. The Homestead Act of 1862 and Timber Culture Act of 73, along with construction of the Santa Fe Railroad rough northern Arizona during the period 1880-1883, doubtedly increased the chances for human-caused fires. n the other hand, this same settlement may have ntributed to a reduction in fire incidence in the area cause in 1883 the Aztec Land and Cattle Company was ported to be grazing 60,000 head of livestock in northern izona. Grazing by other livestock companies was also derway (Faulk 1970). Heavy grazing over large areas uld have the effect of reducing wildfire incidence by lizing grass cover that had, for years, been the primary edium through which fires spread. This theory provides a ssible explanation of why the last recorded fire in the imney Spring area occurred about this time.

Speculating on the ecosystem that was present in the imney Spring area at the time of the last recorded fire 76), and drawing from descriptions by early explorers ooper 1960), it is apparent that most of the stands were en and park-like. Grass and needles were the primary e-carrying medium, and fire intensities, even on high fire-nger days, would have been relatively low. Sparse ground ls would account for the fact that fires could move ough an area without causing appreciable damage to the idual trees. Many of the trees that had previously stained fire scars would have been skipped by the fire cause of the discontinuity in the light surface fuels.

Condition of the forest floor in an area where fires were rning at 2- to 4-year intervals would be in marked contrast what is found today. Ample exposure of mineral soil and increase in available nutrients would have encouraged ablishment of natural pine regeneration as well as oduction of biomass from native grasses and forbs. Ashes l charcoal would have been well incorporated in the neral soil. Seedling mortality would have been high ause of competition for moisture, frost heaving, and suc-sive surface fires.

A precarious balance probably existed between mortality d survival of growing stock needed to perpetuate the nderosa pine type in this area. However, the uneven-age aracter of the pine stands existing today is testimony to e fact that survival materially exceeded mortality as the nds began to come under management and protection in e early 1900's.

In contrast to the stand conditions that existed under the luence of a natural fire regime, the current stand nditions reflect long-established land management licies designed to protect the areas from wildfire. This otection, in the absence of extensive prescribed burning ograms, has resulted in (1) an increase in growing stock to e extent that many areas are now heavily overstocked Schubert 1974); (2) a significant buildup of natural and ivity fuels (Sackett[5]); and (3) an apparent reduction in distribution and density of native grasses because of reased shading and accumulation of pine litter.

[5]Sackett, Stephen S. Reducing natural ponderosa pine fuels using escribed fire: Two case studies. Manuscript in progress. Rocky Muntain Forest and Range Experiment Station, Fort Collins, Colo.

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Dieterich, John H. 1980. Chimney Spring forest fire history. USDA Forest Service Research Paper RM-220, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station ′

Rocky Mountains

Southwest

Great Plains

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Forest Vegetation of the Routt National Forest in Northwestern Colorado: A Habitat Type Classification

George R. Hoffman and Robert R. Alexander

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Abstract

A vegetation classification based on concepts and methods developed by Daubenmire were used to identify 11 forest habitat types in the Routt National Forest. Included were five habitat types in the *Populus tremuloides* series, two in the *Abies lasiocarpa* series, and one each in *Pinus contorta*, *Pseudotsuga menziesii*, *Pinus flexilis*, and *Quercus gambelii* series. A key to identify the habitat types and the management implications associated with each are provided.

Foreword

In 1976, George R. Hoffman began a detailed study of the forest vegetation on the Routt National Forest under a cooperative agreement with the USDA Forest Service, Rocky Mountain Region, and the Rocky Mountain Forest and Range Experiment Station. The results reported here are intended for two primary audiences: forest managers and land use planners who want a working tool to use on the Routt National Forest, and ecologists who want a research tool to use in related studies. Not all readers will find each category of information of equal value.

Robert R. Alexander

Cover photo.—*Populus tremuloides/Thalictrum fendleri* habitat type on the Routt National Forest with several size classes of *P. tremuloides* represented.

SDA Forest Service
esearch Paper RM-221

September 1980

Forest Vegetation of the Routt National Forest in Northwestern Colorado: A Habitat Type Classification

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Contents

Forest Vegetation of the Routt National Forest in Northwestern Colorado: A Habitat Type Classification

George R. Hoffman and Robert R. Alexander

Forest vegetation on the Routt National Forest and adjacent areas has been studied previously to a limited extent, but this study comprehensively categorizes and describes forest habitat types based on quantitative data. Many of the earlier studies of forest vegetation were management oriented or autecologic in scope, but a few are relevant to the present study. Bunin (1975) described vegetation below the subalpine zone, on the west side of the Park Range. Although the sampling methods and nomenclature differ from the study reported here, it is evident that four of the habitat types described in this paper were observed. Adjacent to the Routt to the north, Wirsing and Alexander (1975) described five habitat types on the Medicine Bow National Forest. Two of these also occur on the Routt. On the Crested Butte area south of the Routt, Langenheim (1962) described several mature biotic communities which appear from general descriptions to be similar to three of the habitat types on the Routt.

This cooperative study was started in 1976 to (1) identify and describe forest habitat types in the Routt National Forest; (2) relate habitat types to topographic, edaphic, and climatic factors; (3) describe successional patterns of forest vegetation; and (4) relate Routt habitat types to other Rocky Mountain forests with similar classifications. The habitat type classification[2] completed in 1978 is based on concepts and methods developed by Daubenmire and Daubenmire (1968), Hoffman and Alexander (1976), Reed (1976), and Pfister et al. (1977).

STUDY AREA

Physiography and Geology

The Routt National Forest, in northwestern Colorado (fig. 1), lies within the Southern Rocky Mountain and Wyoming Basin physiographic provinces described by Fenneman (1931). The Colorado Plateau lies immediately to the southwest. The main physiographic features of the region are the north-south trending Park Range-Gore Range mountains and the east-west trending Elkhead Mountains to the west of the Park Range. In the southwestern extreme of the Routt National Forest, flat-topped and steep-sided topography of the White River Plateau is conspicuous. The northeastern segment of the Forest is east of North Park along the western flank of the Medicine Bow Mountains. East of the Park Range-Gore Range is an elliptic-shaped basin of Cretaceous and Tertiary deposits. The basin is mostly unforested and constitutes North Park, and Middle Park which is south of the study area. The Rabbit Ears Range is an east-west oriented anticline that separates North and Middle Parks. Smaller parks are common throughout the Routt National Forest, especially in the area north and west of Hahn's Peak, where much of the surficial deposit is sedimentary of Cretaceous or Tertiary age.

Climate

Precipitation in the Routt National Forest increases with elevation. Mean annual precipitation varies from about 20 inches (52 cm) at 8,600 feet (2,620 m), in the *Populus tremuloides* forest zone, to about 40 inches (102 cm) at 10,000 feet (3,050 m), in the *Abies lasiocarpa* forest zone. At these elevations, somewhat more than one-half the total precipitation falls as snow during the six coldest months of the year.

Mean annual temperature in the *Populus tremuloides* forest zone is about 41° F (5° C), with a January mean of 21° F (−6° C), and a July mean of 59° F (15° C). In the *Abies lasiocarpa* forest zone, mean annual temperature is about 34° F (1° C), with a January mean of 14° F (−10° C) and a July mean of 54° F (12° C).

The limited temperature and precipitation data from published records are useful in characterizing the Routt National Forest in broad general terms. However, mountainous topography produces so much variation in temperature and precipitation that it is difficult to provide any meaningful climatic information for a given locality.

[2]*Hoffman, George R. Forest vegetation on the Routt National Forest, Colorado: A habitat type classification. 135 p. Unpublished report on file at the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo. (FS-RM-MFRWU-1252).*

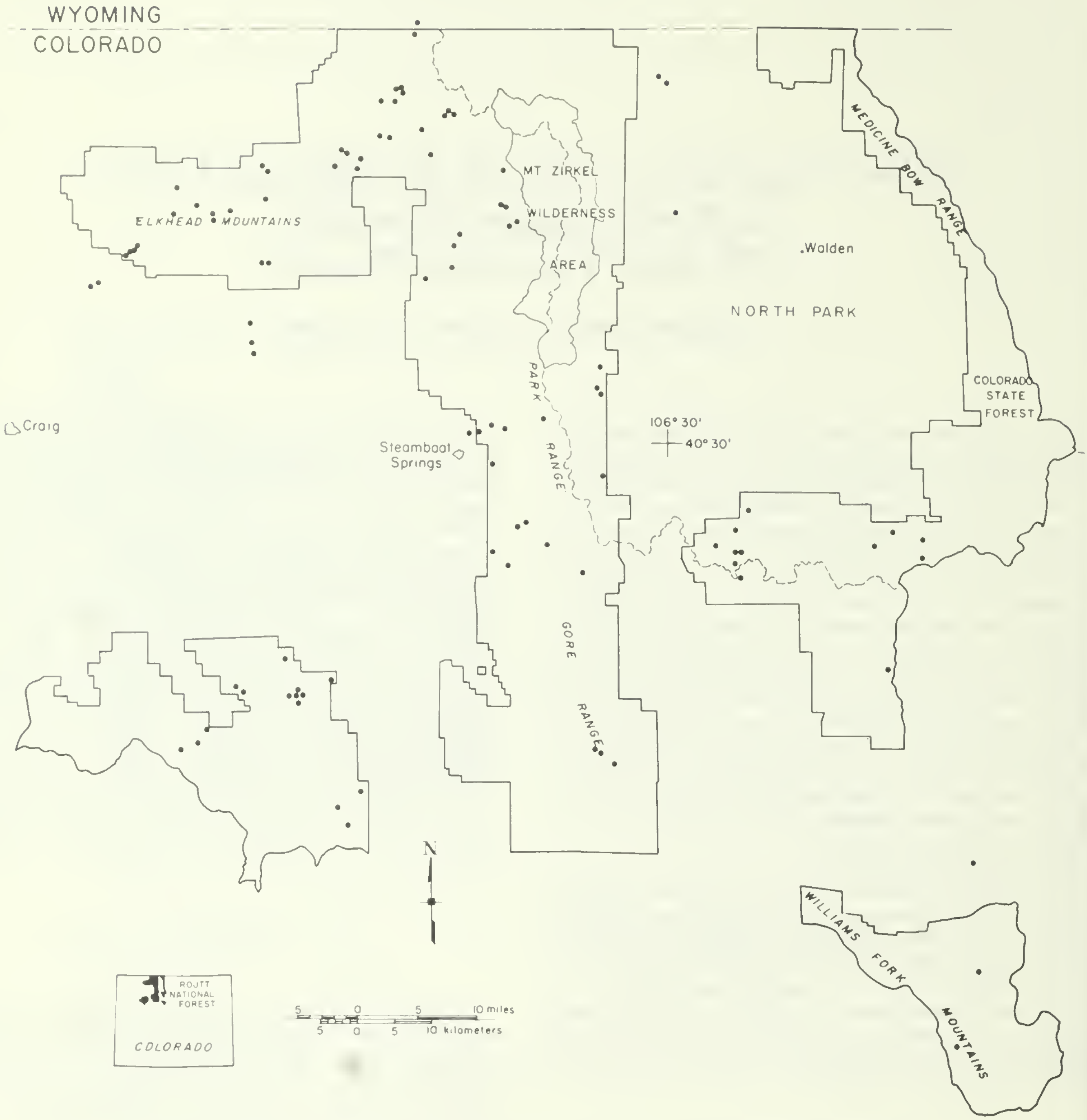

Figure 1.—Routt National Forest, Colorado study area. Intensively sampled sites are indicated by dots.

METHODS

Field Sampling

Preliminary work began in 1976 with a reconnaissance survey of more than 200 sites through the Routt National Forest. Plant species were collected, and a list of possible habitat types and study sites were noted with brief descriptions.

During the summers of 1977 and 1978, 97 stands were intensively sampled. These stands were mostly old-growth and climax or in late seral stages of succession. They were representative of the forest communities characterized by the following tree species: *Quercus gambelii, Pinus flexilis, Pseudotsuga menziesii, Populus tremuloides, Pinus contorta, Abies lasiocarpa*, and *Picea engelmannii.*

In each stand, a 49.2- by 82.0-foot (15- by 25-m) plot was laid out with the long dimension parallel to the contour and was located in the stand to avoid ecotones and disturbances. Each main plot was then subdivided into three

16.4- by 82.0-foot (5- by 25-m) subplots. Within each 4,036-square-foot (375-m²) main plot, all trees taller than 3.28 feet (1 m) were measured at breast height and recorded by 0.328-foot (1-dm) classes. Trees less than 3.28 feet (1 m) tall were counted in two 3.28- by 82.0-foot (1- by 25-m) transects along the inner sides of the central subplot.

Canopy cover of the understory shrubs, forbs, and graminoids was estimated in fifty 7.87- by 19.68-inch (2- by 5-dm) microplots, placed systematically along the inner sides of the central subplot. Canopy coverage of each species was recorded as one of six coverage classes (1-5%, 6-25%, 26-50%, 51-75%, 76-95%, and 96-100%). Also listed were those species not occurring in the 50 microplots, but present within the 4,036-square-foot (375-m²) main plot.

Finally, 25 cores representing the upper decimeter of the mineral soil were collected from each stand. These samples were air dried in the field, then composited for laboratory analysis.

ANALYSIS OF DATA

Tree-size class data were combined according to habitat type, and mean values for each size class in each habitat type were recorded (table A-1).

For each microplot examined, the midpoints of the coverage classes were used to calculate average percent coverage for each shrub, graminoid, and forb species. Frequency was also determined for each species. Coverage and frequency data for all understory species plus site data are shown in appendix tables A-2 through A-11. Species coverage and selected stand characteristics were then transferred to an association table. Stands were arranged and rearranged to group stands with similar floristic composition and climax tree species. Habitat type separation was based on a consideration of both overstory and major shrubs, graminoids, and forbs (Daubenmire 1952, Daubenmire and Daubenmire 1968, Mueller-Dombois and Ellensburg 1974).

Soil texture was determined by a modified Bouyoucos method (Moodie and Koehler 1975). Other soil characteristics determined were pH (using a glass electrode on the saturated soil paste), cation exchange capacity, and exchangeable Ca, Mg, and K on the ammonium acetate extract. N by the Kjeldahl method, OM by a modified Walkley-Black method, and P by the Bray technique were also determined for each sample (Moodie and Koehler 1975).

Nomenclature for plants collected in this study follows Harrington (1954) and Weber (1976). Although plants were collected at various times during the growing season, some taxonomic difficulties persisted. Most of these resulted from hybridization among two or more species which have not been studied systematically to clarify the taxonomy. Other taxonomic difficulties related to lack of flowering specimens. Where considerable variation made it impossible to determine species, genera only were used.

ECOLOGIC TERMS AND CONCEPTS

Because terminology in ecology is not uniformly used or understood, the terms and concepts used in this paper are defined below. Unless stated otherwise, all terms follow usage proposed by Daubenmire and Daubenmire (1968).

"Climax vegetation" is that which has attained a steady state with its environment; species of climax vegetation successfully maintain their population sizes. "Seral communities" are stands of vegetation that have not attained a steady state; current populations of some species are being replaced by other species. All stands of climax vegetation that have the same overstory and understody dominants are grouped into a single "plant association." Plant associations having the same overstory (climax) dominants are grouped into "series" (Hoffman and Alexander 1976).

The Routt National Forest has been disturbed by fire, logging, and grazing for many years. Because of these disturbances, not all of the land area currently supports climax vegetation. However, that land area which either supports, or has the potential of supporting, a single plant association is called a "habitat type." It is possible that much of the area of a habitat type will never attain climax status. Nevertheless, it is important to consider land uuits in terms of their potential status. The practical value of habitat type classifications is only beginniug to be realized in areas of tree productivity, disease and insect susceptibility, potential for producing browse, soil moisture depth, and tree regeneration (Arno and Pfister 1977; Daubenmire 1961, 1973; Layser 1974; Pfister 1972). The habitat type concept offers a useful approach to managing forest resources.

Habitat type is the basic unit in classifying lands or sites based on potential (climax) natural vegetation. Series is the next higher category of classification (Hoffman and Alexander 1976). For example, all habitat types with *Quercus gambelii* the potential climax dominant are grouped into the *Quercus gambelii* series. The series is more than an artificial grouping of habitat types using the potential climax dominant as the convenient thread of continuity. There is an ecologic basis for grouping habitat types into series. For example, *Quercus gambelii* occupies areas that are warmer and drier than areas where *Pseudotsuga menziesii* is climax. Continuing higher into the mountains, *Populus tremuloides*, *Pinus contorta*, *Picea engelmannii*, and *Abies lasiocarpa* successively become the dominant species. In the absence of adequate data for the Routt National Forest, it is assumed that these self-perpetuating populations of dominant trees are related to the macroclimate, whereas the understory vegetation is related more to microclimate and soils. Stands in a series have the same general appearance whether they are in the Routt National Forest or in nearby forests of Colorado and Wyoming. Habitat types within a series are differentiated on the basis of understory vegetation.

Table 1.—Selected topographic and edaphic characteristics of the habitat types in the Routt National Forest

Habitat type	Number of stands sampled	Elevation	Soil texture[1]	pH[1]	Organic matter[1]
		m			%
Pinus flexilis/Juniperus communis	3	2,530-2,615	sand	3.6-6.5	0.9-2.2
Quercus gambelii/Symphoricarpos oreophilus	3	2,240-2,256	loam-loamy sand	6.3	3.5-4.5
Pseudotsuga menziesii/Pachistima myrsinites	2	2,164-2,573	sandy loam	5.9-6.2	3.7
Populus tremuloides/Symphoricarpos oreophilus	7	2,256-2,560	loam-sandy loam	5.9-6.7	4.7-6.4
Populus tremuloides/Thalictrum fendleri	26	2,475-2,957	loamy sand-silt loam	5.2-6.2	3.0-9.5
Populus tremuloides/Heracleum sphondyllium	4	2,444-2,688	sandy loam-clay loam	5.6-6.2	3.9-9.5
Populus tremuloides/Veratrum tenuipetalum	3	2,682	sandy loam-	5.6-6.1	5.5-7.4
Populus tremuloides/Pteridium aquilinum	7	2,475-2,755	loam-sandy loam	5.1-5.9	3.2-6.6
Pinus contorta/Shepherdia canadensis	6	2,755-2,950	sandy loam	5.0-5.3	1.6-3.5
Abies lasiocarpa/Vaccinium scoparium	25	2,365-3,078	sandy loam-silt loam	4.3-5.5	1.9-6.6
Abies lasiocarpa/Carex geyeri	11	2,111-2,952	loam-sandy loam	4.6-6.0	1.8-5.3

[1]*Upper 1 dm of soil*

HABITAT TYPES

Pinus flexilis Series

Pinus flexilis is not an economically important species on the Routt National Forest. It occurs as the sole dominant in isolated, low-density stands at elevations ranging from 8,300 feet (2,530 m) to about 8,580 feet (2,615 m) (table 1).

This series is represented by three plots and one habitat type. All plots were in the northwestern part of the Routt National Forest, on southwest to northwest slopes. Basal areas on the study plots ranged from 54 to 118 square feet per acre (12 to 27 m²/ha). Tree sizes generally ranged from seedlings to 24- to 28-inch (6- to 7-dm) d.b.h. class. Tree population and undergrowth data for *Pinus flexilis* stands are shown in appendix tables A-1 and A-2.

Pinus flexilis/Juniperus communis

Description.—The understory of this habitat type is characterized by the dominance of *Juniperus communis* and the relative scarcity of other species (fig. 2). *Leucopoa kingii* was the only graminoid in all stands sampled. Most of the understory species also were in adjacent plant communities dominated by *Artemisia tridentata.* Soils in this habitat types are shallow, and the parent material is commonly exposed at the ground surface (fig. 3).

Wirsing and Alexander (1975) reported a *Pinus flexilis/Hesperochloa kingii (Leucopoa kingii)* habitat type north of the Routt National Forest in the Medicine Bow National Forest. Their stands were all at high elevation in the *Abies lasiocarpa* zone, though some floristic similarities are evident. In north-central Wyoming, Hoffman and Alexander (1976) reported *P. flexilis* was a seral species in the *Pseudotsuga menziesii* zone of the Bighorn Mountains where it was observed apparently moving into the surrounding shrub-steppe. Farther north, in Montana, Pfister et al. (1977) reported *P. flexilis/J. communis* habitat type east of the Continental Divide at elevations of 4,600 to 8,300 feet (1,405 to 2,530 m). *P. flexilis/J. communis* stands of the present study show little floristic similarity to those in Montana. *P. flexilis* also grows at low elevations at the southern end of the Wind River and Absaroka Mountains (Steele et al. 1979).

Management implications.—This dry habitat type has very low productivity for timber production. Forage value for livestock and big game is low to moderate, with some evidence of use by deer in the spring and fall. Overstory trees adjacent to grasslands may provide cover for wildlife. *P. flexilis* seeds are large and are food for birds and small mammals.

Figure 2.—*Pinus flexilis/Juniperus communis* habitat type. Trees are short and widely spaced. Note: the meter stick in this and subsequent photographs is marked in decimeters.

Figure 3.—Exposed, rocky parent material under a stand of *Pinus flexilis/Juniperus communis* habitat type.

Pseudotsuga menziesii Series

Pseudotsuga menziesii and *Pinus ponderosa* are not widespread or abundant in the Routt National Forest. Bates (1924) suggested that this may be due to repeated fires that converted lands formerly occupied by these species to forests dominated by *Populus tremuloides* and *Quercus gambelii* (table 1).

The *Pseudotsuga menziesii* series was sampled in only two plots and one habitat type that were on steep northwest slopes at elevations of 7,080 to 8,465 feet (2,160 to 2,580 m). *P. menziesii* is climax in some areas and seral to *Abies lasiocarpa* in others. *Populus tremuloides* may be present as a seral species. Basal areas on the study plots range from 113 to 218 square feet per acre (20 to 50 m^2/ha). Tree sizes range from seedlings to the 12- to 16-inch (3- to 4-dm) d.b.h. class. Tree population and undergrowth data for *Pseudotsuga menziesii* stands are shown in appendix tables A-1 and A-3.

Pseudotsuga menziesii/Pachistima myrsinites

Description.—The *Pseudotsuga menziesii/Pachistima myrsinites* habitat type is recognized by the presence and reproductive success of *Pseudotsuga menziesii* and by the abundance and dominance of *Pachistima myrsinites* in the undergrowth (fig. 4). Other important shrub species are *Acer glabrum*, *Amelanchier alnifolia*, *Symphoricarpos oreophilus*, *Vaccinium myrtillus*, and *Quercus gambelii*. The most conspicuous herbaceous plants are *Arnica cordifolia*, *Aster engelmannii*, *Epilobium angustifolium*, *Lathyrus leucanthus*, and *Osmorhiza* sp. No *Pseudotsuga*-dominated habitat types were reported in the Medicine Bow National Forest (Wirsing and Alexander 1975). In the Wind River Mountains, Reed (1976) described a *P. menziesii/Symphoricarpos oreophilus* habitat type, and Steele et al. (1979) described a *P. menziesii/Acer glabrum* habitat type which is somewhat similar to the *Pseudotsuga menziesii/Pachistima myrsinites* habitat type on the Routt. In the Bighorn Mountains, *Pseudotsuga* is widespread and dominates the *P. menziesii/Berberis repens* and *P. menziesii/Physocarpus monogynous* habitat types (Hoffman and Alexander 1976).

Management implications.—Little information is available on the management of this limited habitat type. Timber productivity is below the average for *Pseudotsuga*, because it grows in relatively dry situations. Regeneration is likely to be difficult to obtain if stands are clearcut. Group selection and shelterwood cuttings approximate the regeneration patterns observed in natural forests. Livestock forage production is low, and the potential for increasing it is not very great. Big game may browse the shrub species heavily at times. Shrub species can be increased by maintaining low overstory basal areas. The potential for increasing natural runoff is not very great because of the limited area occupied by the habitat type.

Figure 4.—*Pseudotsuga menziesii/Pachistima myrsinites* habitat type on a steep slope. *Populus tremuloides* is the codominant tree in this stand.

Quercus gambelii Series

Quercus gambelii occupies a zone between the *Artemisia tridentata*-dominated shrub-steppe and the wetter forest habitats upslope (table 1). In some locations, *Q. gambelii* is adjacent to or intermingled with *Populus tremuloides*-dominated forests. *Q. gambelii* frequently forms dense, nearly impenetrable thickets with associated shrubs. In other locations, small-statured forests with a recognizable undergrowth develop.

This series is represented by three plots, located on southeast to northwest slopes at 7,350 to 7,400 feet (2,240 to 2,256 m) elevation. Only one habitat type has been recognized in this series. Basal areas on the study plots ranged from 44 to 157 square feet per acre (10 to 36 m^2/ha). Tree sizes varied from seedlings to mostly the 4- to 8-inch (1- to 2-dm) d.b.h. class, with an occasional larger stem. Tree population and undergrowth data for *Quercus gambelii* stands are recorded in appendix tables A-1 and A-4.

Quercus gambelii/Symphoricarpos oreophilus

Description.—The understory of this habitat type characteristically has both woody and herbaceous species, but is dominated by *Symphoricarpos oreophilus* (fig. 5). *Amelanchier alnifolia* and *Prunus virginiana melanocarpa* were shrubs present in all stands sampled. *Artemisia tridentata* was present in two stands. Among the constant herbaceous species present were *Poa interior*, *Achillea millefolium*, *Erigeron elatior*, and *Vicia americana*. *Agropyron trachycaulum*, *Bromus ciliatus*, *Carex geyeri*, *Poa pratensis*, *Stellaria jamesiana*, *Thlaspi montanum*, and *Wyethia amplexicaulis* were all present in two stands. A number of the undergrowth species in this habitat type were present under *Q. gambelii* in west-central Colorado (Brown 1958). Wirsing and Alexander (1975) did not identify a *Q. gambelii* habitat type on the Medicine Bow National Forest in southern Wyoming, but did recognize a xerophytic *Q. gambelii* community in the dry foothills and canyons.

Management implications.—Little is known about this dry habitat type. It has little value for timber or water production. Value for livestock varies with the amount of graminoids in the understory. It provides spring and fall habitat for big game and food and cover for nongame animals.

Populus tremuloides Series

Populus tremuloides is the most abundant tree species in the Routt National Forest. It occurs from low elevation, often adjacent to or intermingled with *Quercus gambelii*, to near timberline (table 1). It is most vigorous at intermediate elevations where temperature and moisture regimes are moderate.

Figure 5.—*Quercus gambelii/Symphoricarpos oreophilus* habitat type. Most *Quercus* stands occur as dense thickets outside the national forest boundary.

There has been considerable discussion regarding the role of *P. tremuloides* as a climax and/or seral species in the Rockies; both assessments may be correct. In some areas, *P. tremuloides* dominates sites where fires have destroyed coniferous forests. In time, conifers gradually replace *P. tremuloides* (fig. 6). Succession to coniferous forest is apparently slowed significantly by changes in soil resulting from site occupancy by the deciduous *Populus*. In other areas, *P. tremuloides* forests appear to be climax without evidence of conifer invasion. According to Mueggler (1976), complete conversion of *Populus* stands to coniferous climax forest may require more than 1,000 fire-free years. The origin of both seral and climax *P. tremuloides*-dominated forests may be the same—destruction of coniferous forest by repeated fires.

Many *P. tremuloides* forests are even-aged; the trees originate from sprouts after a disturbance. Baker (1925) suggested that in stands where older trees die naturally over a short time span, an even-aged replacement stand may develop. Other stands are uneven-aged, and sprouts apparently provide sufficient numbers of young trees to perpetuate the species indefinitely. Two-storied stands are also relatively common and can develop when surface fires burn quickly through mature stands, thereby stimulating sprouting.

This series is represented by 47 plots, located on all aspects at elevations of 7,380 to 9,710 feet (2,250 to 2,960 m). Five habitat types were recognized. Basal areas on the study plots range from 35 to 314 square feet per acre (8 to 77 m^2/ha). Tree sizes usually ranged from seedlings to the 12- to 16-inch (3- to 4-dm) d.b.h. class. Occasionally there were scattered trees in the 20- to 24-inch (5- to 6-dm) d.b.h. class. Not all d.b.h. classes were represented on each plot (fig. 7). Stand ages ranged from 45 to 160 years, with a median age of about 80 years on most plots. Tree population and undergrowth data for *Populus tremuloides* stands are shown in appendix tables A-1, A-4, A-5, and A-6.

Populus tremuloides/Symphoricarpos oreophilus

Description.—The *Populus tremuloides/Symphoricarpos oreophilus* habitat type, represented by seven stands, is recognized by the consistent presence and reproductive success of *P. tremuloides* and the abundance and dominance of *S. oreophilus* in the undergrowth (fig. 8). In four of the stands sampled, *P. tremuloides* was the sole dominant tree species; in three others, *Q. gambelii* was a codominant. This habitat type occupies the driest habitats in the *P. tremuloides* zone. All stands sampled were at the lower edge of this zone. In the direction of drier habitats, *P. tremuloides* is replaced by *Quercus gambelii* to form the *Q. gambellii/S. oreophilus* habitat type.

In addition to *S. oreophilus*, important shrubs are *Amelanchier alnifolia*, *Prunus virginiana melanocarpa*, *Rosa woodsii*, and *Mahonia repens*. The most important species in the rich mixture of graminoids and forbs are *Bromus ciliatus*, *Carex geyeri*, *Elymus glaucus*, *Melica spectabilis*, *Poa interior*, *P. pratensis*, *Achillea millefolium*, *Agastache urticifolia*, *Galium boreale*, *Geranium* sp.,

Figure 6.—*Abies lasiocarpa* successfully reproducing and invading a *Populus tremuloides*-dominated forest.

Figure 7.—*Populus tremuloides*-dominated habitat type with only the 1- to 2-dm-diameter and 3- to 4-dm-diameter classes represented.

Figure 8.—*Populus tremuloides/Symphoricarpos oreophilus* habitat type. *Populus* is the only tree in this stand. *Symphoricarpos* provides 40% coverage in the undergrowth.

Lathyrus leucanthus, Osmorhiza sp., *Stellaria jamesiana, Thalictrum fendleri, Valeriana occidentalis,* and *Vicia americana.*

Bunin (1975) recognized a *Symphoricarpos oreophilus*-dominated undergrowth on the west slope of the Park Range in the Routt. In the Medicine Bow National Forest and in the Bighorn Mountains, there are no understory vegetation associations dominated by *Symphoricarpos* (Wirsing and Alexander 1975, Hoffman and Alexander 1976). In the Wind River Mountains, Reed (1976), and in Utah, Henderson et al. (1977), reported *Populus tremuloides/S. oreophilus* habitat types with similar associated undergrowth. In western Wyoming, Youngblood (1979), described this vegetation association as a community type.

Management implications.—Timber productivity is low to moderate in this dry habitat type. Clearcutting and regenerating a new stand is usually the preferred way to handle these stands. Annual precipitation varies from 18 to 24 inches (46 to 61 cm), with about 9 to 12 inches (23 to 30 cm) of runoff. Potential for increasing streamflow under management is unknown. This habitat type is spring and fall big game range, and use may be heavy. In years of low snowfall, it may be used all winter. The habitat type is summer range for livestock. Under proper grazing management, herbage production may be as high as 500 to 800 pounds per acre (560 to 896 kg/ha), with high protein browse important. This habitat type has fairly good scenic quality, but generally with less favorable color contrast than with mixed *Populus*-conifer stands. Mature and open stands generally are more visually attractive, with the shrub understory providing both texture diversity and variety in seasonal color.

Populus tremuloides/Thalictrum fendleri

Description.—This habitat type, represented by 26 stands, is the most widespread of the *Populus*-dominated habitat types in the Routt National Forest (fig. 9). It is recognized by the consistent reproductive success of *Populus tremuloides* and high coverage of *Thalictrum fendleri* in the undergrowth. In 17 of the stands sampled, *P. tremuloides* was the only tree species. In most of the other stands, there was a scattering of seedlings of *Abies lasiocarpa, Picea engelmannii,* and *Pinus contorta,* but no clear evidence that these stands were moving toward a climax dominated by conifers. Only one *Populus* stand resembled a seral community. Most of the stands in this habitat type appear to develop into uneven-aged or broad-aged stands that are self-perpetuating.

The undergrowth is primarily a rich mixture of herbaceous species in three distinct strata (fig. 10). Important species in the lowest stratum are: *Carex geyeri, Achillea millefolium, Androsace septentrionalis, Galium boreale, Nemophila breviflora, Stellaria jamesiana, Taraxacum* sp., and *Viola nuttallii.* The intermediate stratum of species, about 16 to 24 inches (4 to 6 dm) high, includes *Melica spectabilis, Poa interior, Erigeron elatior, Geranium richardsonii, Lathyrus leucanthus, Lupinus argenteus rubricaulis, Thalictrum fendleri,* and *Vicia americana.* The tallest stratum, commonly 24 to 36 inches (6 to 9 dm) tall, includes *Bromus ciliatus, Elymus glaucus, Aster engelmannii, Delphinium barbeyi, Ligusticum porteri,* and *Osmorhiza* sp.

Bunin (1975) also recognized the *Populus tremuloides/Thalictrum feldleri* habitat type on the west side of the Park Range. Langenheim (1962) described *Populus*-dominated forests in the Crested Butte area that appear similar to the *P. tremuloides/T. fendleri* habitat type. The *Populus tremuloides/Carex geyeri* habitat type of the Medicine Bow National Forest, described by Wirsing and Alexander (1975), shows some similarities to the *P. tremuloides/T. fendleri* habitat type. Youngblood (1979) described a *P. tremuloides/T. fendleri* habitat type in western Wyoming, but in the Wind River Mountains and Bighorn Mountains, no plant associations similar to this habitat type were found (Hoffman and Alexander 1976, Reed 1971).

Management implications.—The *P. tremuloides/T. fendleri* habitat type is the most productive for timber in the *Populus* series. Site quality ranges from average to high. Clearcutting in patches or small blocks and regenerating new stands is the most effective way to handle these stands. This habitat type is the best summer range for big game and for sheep. Forage production under proper grazing management can be as high as 3,000 pounds per acre (3,360 kg/ha). It also provides habitat for numerous nongame animals, but the management implications for them are unknown. This habitat type has the most visually appealing foreground of all *Populus*-dominated habitat types because of the usually wide spacing with large tree diameters and the abundance of wildflowers in the undergrowth. Soils are well developed and erosion is usually not a problem except on deteriorated ranges. In some situations, potential for mass movement appears to be high, especially if the overstory is removed in large clearcut blocks. Annual precipitation is 25 to 40 inches (64 to 102 cm), with about one-half becoming runoff. Potential for increasing streamflow under management is unknown.

Populus tremuloides/Heracleum sphondyllium

Description.—The *Populus tremuloides/Heracleum sphondyllium* habitat type, represented by only four stands all on north and northeast slopes, is more limited than the *P. tremuloides/T. fendleri* habitat type (fig. 11). *P. tremuloides* was the only tree species found in three stands. The remaining stand contained a few small *Abies lasiocarpa.* The understory is dominated by *H. sphondyllium* and species common to the undergrowth of the *P. tremuloides/T. fendleri* habitat type. *H. sphondyllium,* however, usually overtopped all other species. It produced most of the coverage where grazing by livestock was excluded from the stands. The most abundant of other undergrowth species are *Thalictrum fendleri, Bromus ciliatus, Elymus glaucus, Poa palustris, Delphinium barbeyi, Geranium richardsonii, Ligusticum porteri,* and *Mertensia ciliata.*

Figure 9.—*Populus tremuloides/Thalictrum fendleri* habitat type. In this stand, *Populus* occur in all diameter classes up to 5 to 6 dm.

Figure 10.—Undergrowth in the *Populus tremuloides/Thalictrum fendleri* habitat type. Conspicuous plants are *T. fendleri*, in the lower half of the photograph, *Heracleum sphondyllium*, at lower center just to the right of the meter stick, *Geranium richarsonii* in flower, *Elymus glaucus*, and *Bromus ciliatus*.

Figure 11.—*Populus tremuloides/Heracleum sphondyllium* habitat type. This stand has been protected from grazing since 1941.

Bunin (1975) did not recognize a *P. tremuloides/H. sphondyllium*-dominated vegetation, but the best examples of this habitat type in the Routt are not on the west side of the Park Range. Langenheim (1962) reported *Heracleum* sp. in about half the *Populus*-dominated stands observed in the Crested Butte area in Colorado. North of the Routt, *Heracleum* sp. were reported in forests dominated by *P. tremuloides* by Youngblood (1979), but not by Hoffman and Alexander (1976), Reed (1971), or Wirsing and Alexander (1975).

Management implications.—This habitat type is quite similar in management implications to the *P. tremuloides/ T. fendleri* habitat type in the Routt National Forest, and the two can be treated in the same manner.

Populus tremuloides/Veratrum tenuipetalum

Description.—This habitat type is restricted to very wet sites (fig. 12). Only three stands were sampled. *P. tremuloides* was the only tree species in one stand and was the dominant self-reproducing tree species in the other stands. The undergrowth is characterized by the abundance of *Veratrum tenuipetalum*. Other important undergrowth species are *Bromus ciliatus*, *Poa palustris*, *Hydrophyllum capitatum*, *Ligusticum porteri*, *Mertensia ciliata*, and *Thalictrum fendleri*.

Weber (1976) and others have suggested that *Veratrum tenuipetalum* is an indicator of site deterioration and forms dense stands on overgrazed subalpine meadows. In the present study, *V. tenuipetalum* grew in wet habitats, not widely distributed within the *Populus tremuloides* zone. The stands studied had not been grazed recently, and whether past grazing history in this habitat type significantly effected the composition of undergrowth is not known.

No similar habitat types have been reported in *Populus*-dominated stands in the Medicine Bow National Forest or Wind River and Bighorn Mountains (Hoffman and Alexander 1976, Reed 1971, Wirsing and Alexander 1975).

Management implications.—This habitat type is restricted in area. The management implications are similar to those of the *P. tremuloides/T. fendleri* habitat type. However, if *Veratrum tenuipetalum* is an indicator of site deterioration resulting from overgrazing, the potential for timber and forage production and infiltration is less than in the *P. tremuloides/T. fendleri* habitat type, and the potential for increased erosion, surface runoff, and mass movement is greater. Consequently, more care must be exercised in locating and building roads and in harvesting timber.

Populus tremuloides/Pteridium aquilinum

Description.—The *Populus tremuloides/Pteridium aquilinum* habitat type is represented by seven stands (fig. 13); all study sites were located in the Park Range and

Figure 12.—*Populus tremuloides/Veratrum tenuipetalum* habitat type *V. tenuipetalum* is the major undergrowth species.

Figure 13.—*Populus tremuloides/Pteridium aquilinum* habitat type. *Populus* is the only tree species and occurs in five diameter classes. *Pteridium aquilinum* provides 74% coverage in the undergrowth.

Elkhead Mountains on northwest, east, and south slopes in topographic positions that seemingly were poorly drained. Young trees of *A. lasiocarpa* were present in three stands, but their successional status is unclear. In addition to *Populus tremuloides* dominance as the most prolific self-reproducing tree species, this habitat type is recognized by the dominance of *Pteridium aquilinum* in the undergrowth. Other important understory species are *Bromus ciliatus*, *Carex geyeri*, *Elymus glaucus*, *Aster engelmannii*, *Delphinium barbeyi*, *Galium borale*, *Geranium richardsonii*, *Lathyrus leucanthus*, *Ligusticum porteri*, *Osmorhiza* sp., *Stellaria jamesiana*, *Thalictrum fendleri*, and *Vicia americana*.

In the Routt National Forest, the *Populus tremuloides/Pteridium aquilinum* habitat type has a rather restricted distribution. It was not observed south of 40°20′ N latitude. Bunin (1975) also observed this habitat type on the west slope of the Park Range. Morgan (1969) reported no *Pteridium aquilinum* in stands of *Populus* forests in Gunnison County, Colorado, even though a stand in which *Pteridium* was very abundant in the undergrowth was photographed. Langenheim (1962) also did not report *P. aquilinum* in *Populus* forests near Crested Butte. Northward in Wyoming, Idaho, and Montana, no *Populus/Pteridium* habitat type has been reported (Hoffman and Alexander 1976; Pfister et al. 1977; Reed 1971; Steele et al. 1975, 1979; Wirsing and Alexander 1975; Youngblood 1979).

Management implications.—The management implications of this habitat type are similar to the *Populus tremuloides/Thalictrum fendleri* habitat type, with the same potential for reduced benefits and increased risks from management activities as noted for the *P. tremuloides/Veratrum tenuipetalum* habitat type, because *Pteridium aquilinum* is also considered to be an indicator of site deterioration.

Pinus contorta Series

Pinus contorta in the Routt National Forest and elsewhere in the Rocky Mountains is usually attributed to widespread and repeated fires. There is less agreement on its successional status. Many ecologists and foresters consider *P. contorta* a seral species, which, in the absence of fire, would be replaced by forests dominated by *Picea engelmannii, Abies lasiocarpa*, and *Pseudotsuga menziesii* (Clements 1910, Daubenmire 1943, Mason 1915). More recently, investigators have concluded that *Pinus contorta* is climax or at least a long-lived subclimax species in certain topoedaphic situations. Moir (1969) reported it to be climax within the upper montane zone of the Front Range of Colorado. Hoffman and Alexander (1976) described climax *P. contorta* forests in the Bighorn Mountains, Wyoming, occurring on soils derived from granites, with low nutrient and waterholding capacities. Climax *P. contorta* forests are described in the Wind River and Absaroka Mountains, western Wyoming, by Reed (1976) and Steele et al. (1979). Pfister et al. (1977) reported apparently stable and climax *Pinus contorta* forests in Montana.

In the Routt National Forest, *P. contorta* was not encountered in *Pseudotsuga menziesii* forests and only rarely in *Populus tremuloides* forests; but it was a common seral species in *Picea engelmannii/Abies lasiocarpa* forests. In fact, some of the largest *Pinus contorta* encountered on the Routt National Forest were in *Abies*-dominated habitat types (fig. 14). Seral *P. contorta* is more likely to be even-aged and bear a high proportion of serotinous cones. Where *P. contorta* is the dominant self-reproducing species, it may exhibit a population structure of several age classes, and has no competition from its common associates (table 1). Climax *P. contorta* stands are more likely to contain a higher proportion of trees bearing nonserotinous cones.

In some areas on the Routt National Forest, especially on dry poor sites, *P. contorta* forms dense dog-hair stands with little undergrowth. In these situations, *P. contorta* may be a seral species that will occupy the site for hundreds of years simply because there is no seed source of climax species available for reinvasion.

This series is represented by six stands located at elevations of 9,040 to 9,680 feet (2,755 to 2,950 m) on soils derived from sedimentary rock. Only one *P. contorta*-dominated habitat type has been recognized. Basal areas on the study plots ranged from 118 to 386 square feet per acre (57 to 89 m^2/ha). Tree sizes ranged from seedlings to the 12- to 16-inch (3- to 4-dm) d.b.h. class, with an occasional tree in the 16- to 20-inch (4- to 5-dm) d.b.h. class. Age varied from 100 to 200 years. Tree population and undergrowth data are shown in appendix tables A-1 and A-8.

Pinus contorta/Shepherdia canadensis

Description.—All *P. contorta* stands sampled were in the southern part of the Routt National Forest. Five stands were located on well drained soils derived from sandstone/conglomerate. The remaining stand was on soil derived from Holocene landslide substrate.

The constant presence and reproductive success of *P. contorta*, the absence of any significant reproduction of other tree species, and the understory dominance of *Shepherdia canadensis* are the diagnostic features of this habitat type (fig. 15). Other important shrub species are *Juniperus communis*, *Pachistima myrsinites*, *Rosa* sp., *Vaccinium myrtillus*, and *V. scoparium*. *Arnica cordifolia* is the most common forb in the undergrowth.

Reed (1971) described a *Pinus contorta/Poa nervosa* habitat type in the Wind River Mountains in which *Shepherdia canadensis*, *Juniperus communis*, and *Rosa acicularis* were present in about half the stands. This habitat type had a more luxuriant undergrowth and occurred on more favorable sites than *Pinus contorta/S. canadensis* habitat type in the Routt. In the Wind River and Absaroka Mountains, Steele et al. (1979) described an *Abies lasiocarpa/Arnica cordifolia* habitat type that is similar to the *P. contorta/S. canadensis* habitat type on the Routt National Forest. In the Bighorn Mountains, Hoffman and Alexander (1976) described an *Abies lasiocarpa/Shepherdia canadensis* habitat type which occurred on north-facing slopes, on the west side of the mountains. It

Figure 14.—Seral, old growth *Pinus contorta* in an *Abies lasiocarpa/Vaccinium scoparium* habitat type where *Picea engelmannii* is co-climax.

Figure 15.—*Pinus contorta/Shepherdia canadensis* habitat type. *Juniperus communis* is present at the left side of the photograph.

was characterized by the presence of *Vaccinium scoparium* beneath *Shepherdia canadensis*-dominated undergrowth. A similar habitat type was not observed in the Medicine Bow Mountains (Wirsing and Alexander 1975) or in Montana (Pfister et al. 1977).

Management implications.—The *Pinus contorta/ Shepherdia canadensis* habitat type is reasonably productive for timber, even though site indexes are likely to be average to below average (Alexander 1966). Even-aged management under either a clearcutting or shelterwood cutting alternative is recommended for most stands (Alexander 1974). A shelterwood system has the advantages of better meeting wildlife cover and visual management requirements while at the same time providing shade needed to conserve soil moisture and help control overstocking. It also provides some control over dwarf mistletoe, although clearcutting is a more effective silvicultural control. Clearcutting can result in either too much or too little reproduction, depending on the cone habit, amount of seed available, and slash disposal treatments (Alexander 1974). If a clearcut option is used in stands with nonserotinous cones, openings should be in the form of small 3- to 5-acre (1.24- to 2.02-ha) patches or narrow 400-foot (122 m) wide strips where natural regeneration is desired. Large clearcut openings will require fill-in planting. In stands with serotinous cones, clearcut openings up to 40 acres (16 ha) may be used if the stand is heavily infected with mistletoe. Care must be used in slash disposal in these stands so that the seed source is not destroyed.

Uneven-aged management under individual tree or group selection cutting can reduce stand susceptibility to mountain pine beetles by removing the most susceptible host trees. Group selection cutting is a possibility in stands with irregular structure, but individual tree selection in stands not attacked by mountain pine beetles is generally appropriate only in recreation areas. Growth will be substantially reduced, however, with either uneven-aged cutting method.

In young *P. contorta* pole stands, thinning is needed to reduce basal area and improve soil moisture conditions. Basal area levels of 120 to 160 are most appropriate for timber production (Alexander and Edminster 1980a).

Forage production is usually increased for a short time after clearcutting, but the potential for increasing forage production for either livestock or big game is limited in this habitat type.

Natural runoff in the *P. contorta/Shepherdia canadensis* habitat type is 10 to 15 inches (25 to 38 dm) annually. Much of the precipitation falls as snow. Streamflow can be substantially increased by clearcutting about one-third of the area in small patches interspersed with uncut timber. Other cutting methods are not likely to result in significant increases in natural runoff (Leaf 1975, Leaf and Alexander 1975).

Abies lasiocarpa Series

This series, represented by 36 plots, occupies the highest coniferous forest zone in the Routt National Forest (table 1). These forests—dominated by *Abies lasiocarpa* and *Picea engelmannii*—are usually referred to as the subalpine zone. In the Routt National Forest, as throughout much of the Rocky Mountains, the subalpine zone is widespread and supports forests of considerable importance. These forests are found on the Routt National Forest on all aspects. Stands sampled were from 7,760 to 10,000 feet (2,365 to 3,078 m) a span of 2,340 feet (713 m) elevation. This zone has been reported to be, generally, 2,000 feet (610 m) in elevational extent (Daubenmire 1943). In the Medicine Bow Mountains, Oosting and Reed (1952) reported spruce-fir vegetation occurred from 8,200 feet (2,500 m) in moist canyons to 11,600 feet (3,535 m). In the Routt National Forest, the lower elevational limits of *Abies lasiocarpa*-dominated forests and the upper elevational limits of the *Populus tremuloides*-dominated forests overlap, though aspect and soil play some part in the forest distribution.

The habitat types described in this series are all named for *Abies lasiocarpa* as the climax dominant to be consistent with common usage elsewhere (Daubenmire and Daubenmire 1968, Hoffman and Alexander 1976, Pfister et al. 1977, Reed 1976, Wirsing and Alexander 1975). In the Routt National Forest, *Picea engelmannii* is a co-climax dominant, with little evidence that it will ever be completely replaced by *A. lasiocarpa*. Young *A. lasiocarpa* usually outnumber the young *P. engelmannii*, because *A. lasiocarpa* is more tolerant and reproduces by both layering and from seeds, whereas *P. engelmannii* reproduces only from seed. Because *P. engelmannii* is long-lived, they are nearly always the larger trees in the stand. In most stands, *Pinus contorta* and *Populus tremuloides* are present as seral species. After disturbance, both *A. lasiocarpa* and *Picea engelmannii* can reestablish immediately with or without *Pinus contorta* and/or *Populus tremuloides*, depending on the type of disturbance and availability of seed or sprouting capacity.

Two habitat types were recognized in this series. Stands sampled ranged from 65 to more than 300 years old at breast height. Basal areas ranged from 126 to 340 square feet per acre (29 to 78 m²/ha) (fig. 16). Tree sizes ranged from seedling to the 24- to 28-inch (6- to 7-dm) d.b.h. classes with an occasional tree in the more than 30-inch (8-dm) d.b.h. class. Tree population and undergrowth data are shown in appendix tables A-1, A-7 and A-9.

Abies lasiocarpa/Vaccinium scoparium

Description.—This habitat type, represented by 25 stands generally located on northwest-by-east and southwest-by-northwest aspects, is recognized by the almost constant presence and reproductive success of *Abies lasiocarpa* and by the abundance and understory dominance of *Vaccinium scoparium* with a constancy of 100% and an average coverage of 39% (fig. 17). *Picea engelmannii* is present as a self-reproducing co-climax species.

The overstory is dominated by *A. lasiocarpa* and *P. engelmannii*. *Pinus contorta* is an important seral species (fig. 18). *Populus tremuloides* is an occasional minor seral species. Ground cover which varies from sparse to lux-

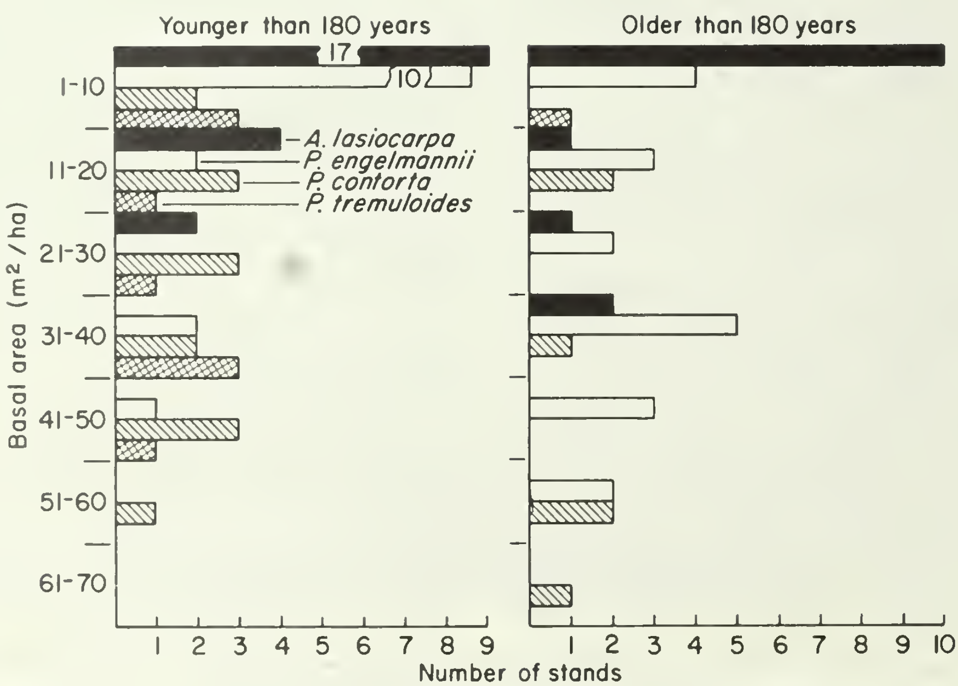

Figure 16.—Basal areas of tree species in *Abies lasiocarpa*-dominated habitat types. Data show relationships between stand age and numbers of stands in which species occur.

Figure 17.—*Abies lasiocarpa/Vaccinium scoparium* habitat type. *A. lasiocarpa* and *Picea engelmannii* are well represented in several size classes, including seedlings.

Figure 18.—*Abies lasiocarpa/Vaccinium scoparium* habitat type in which seral *Pinus contorta* still dominates the overstory. *A. lasiocarpa* and *Picea engelmannii* are the only self-reproducing tree species and will replace *Pinus contorta*.

uriant also includes the following important species: *Arnica cordifolia*, *Pachistima myrsinites*, *Ramischia secunda*, *V. myrtillus*, and *Carex geyeri* (fig. 19).

The *A. lasiocarpa/V. scoparium* habitat type, or others very similar to it, occur throughout a large region of the Rocky Mountains (Hoffman and Alexander 1976; Pfister et al. 1977; Steele et al. 1975, 1979; Wirsing and Alexander 1975). However, there is considerable variability in the coverage of *V. scoparium* within this habitat type. For example, more broad-leaved herbaceous dicots occur in this habitat type on the western slope of the Rockies than on the eastern slope.

Management implications.—Timber productivity varies considerably (Alexander 1967). Understory vegetation changes slowly after major disturbance, and competition is not severe between tree seedlings and understory vegetation, except where coverage of herbaceous dicots is high. There may be a manageable stand of advanced reproduction in much of this habitat type. While most silvicultural systems can be used (Alexander 1974), removal of the mature overstory in these mixed stands may result in an even-aged replacement stand of seral *Pinus contorta*, unless extreme care is taken in logging to protect advanced *Abies lasiocarpa* and *Picea engelmannii*. In mixed stands where *Pinus contorta* makes up part of the overstory, a shelterwood system that removes most of the *P. contorta* in the first cut can be used to maintain or increase the proportion of *A. lasiocarpa* and *Picea engelmannii* in the stand. Clearcutting is more likely to eliminate *P. engelmannii* on southerly exposures than on other aspects. Where protection from direct solar radiation and excessive soil moisture losses is necessary for survival of *P. engelmannii* seedlings, shelterwood is the only appropriate even-aged system. Uneven-aged management with group selection and/or individual tree selection cutting can be used in irregular-age stands, or where the combination of openings and high forest is required to enhance recreational opportunities and amenity values. Group selection is likely to perpetuate the existing species mix, while individual tree selection will favor *Picea engelmannii*, especially if the initial cutting removes a large proportion of *Pinus contorta*.

The *Abies lasiocarpa/Vaccinium scoparium* habitat type is not heavily used by livestock, but is big game summer range. It occupies areas with the greatest potential for water yield (up to 20 inches (50 cm) of natural runoff annually) in the Routt National Forest. Small patch (3- to 5-acre (1.24- to 2.02-ha)) or strip (400-foot (122-m)) clearcuts results in greater forage production for big game animals and larger increases in water available for streamflow than either shelterwood, group selection, or individual-tree selection cutting (Alexander 1977, Alexander and Edminster 1980b, Leaf 1975, Leaf and Alexander 1975, Regelin and Wallmo 1978, Wallmo 1969, Wallmo et al. 1972). Since forage production begins to decline in about 15 to 20 years, and water production in 20 to 30 years, new openings must be cut periodically to maintain these increases.

Figure 19.—Undergrowth in the *Abies lasiocarpa/Vaccinium scoparium* habitat type characteristically has few species, though *V. scoparium* is dense. *V. myrtillus*, *Arnica cordifolia*, and an *Abies lasiocarpa* seedling are also present in this stand.

Abies lasiocarpa/Carex geyeri

The *Abies lasiocarpa/Carex geyeri* habitat type, represented by 11 stands generally on northwest to south aspects, is distinguished by the dominance of *C. geyeri* in the undergrowth, the scarcity of *Vaccinium scoparium*, and the absence of *V. myrtillus* (fig. 20). The overstory dominants are *A. lasiocarpa* and *Picea engelmannii*. *Pinus contorta* and *Populus tremuloides* are seral species in most stands, with *P. tremuloides* a much more important seral species in the younger stands than in the *A. lasiocarpa/V. scoparium* habitat type; however, neither seral species shows any significant evidence of reproducing (fig. 21). Important undergrowth species in addition to *C. geyeri* are *Mahonia repens*, *Rosa* sp., *Pachistima myrsinites*, *Arnica cordifolia*, *Fragaria* sp., *Lathyrus leucanthus*, *Lupinus argenteus*, *Osmorhiza* sp., and *Vicia americana*.

This habitat type occurs at lower elevations and in drier situations than the *Abies lasiocarpa/Vaccinium scoparium* habitat type. Most stands were located at about 8,600 feet (2,620 m) on soils derived from a variety of parent materials. At higher elevations, the *A. lasiocarpa/C. geyeri* habitat type occurs on south and east slopes whereas the *A. lasiocarpa/V. scoparium* habitat type is generally on northwest to northeast slopes at upper elevations (fig. 22).

Steele et al. (1979) and Wirsing and Alexander (1975) reported an *A. lasiocarpa/C. geyeri* habitat type in Yellowstone National Park, the Teton National Forest, and the Medicine Bow Mountains, Wyoming, but it does not occur in the Wind River or Bighorn Mountains, Wyoming (Hoffman and Alexander 1976, Reed 1976). In Montana, an *A. lasiocarpa/C. geyeri* habitat type is a minor habitat type, occurring on cold, dry sites (Pfister et al. 1977). The habitat type does not occur in eastern Washington or northern Idaho (Daubenmire and Daubenmire 1968), but is common in central Idaho on granitic soils (Steele et al. 1975).

Management implications.—Understory vegetation in this habitat type recovers slowly from major disturbance. Reproduction in this dry, cold habitat type is likely to be more difficult to obtain, and competition between tree seedlings and understory vegetation is more severe than in the *A. lasiocarpa/V. scoparium* habitat type. Timber productivity is average to below average. Cutting methods applicable are similar to those suggested for the *A. lasiocarpa/V. scoparium* habitat type. Where there is an appreciable amount of either *Pinus contorta* or *Populus tremuloides* in the stands, clearcutting is likely to increase their representation in the new stand. This habitat type provides forage for livestock and big game. Heavy grazing may reduce the *Carex* cover and expose soils difficult to revegetate. Natural runoff (15 inches (38 cm)) is less than in the *A. lasiocarpa/ V. scoparium* habitat type, but can be increased significantly using the same cutting methods suggested for *A. lasiocarpa/V. scoparium* habitat type.

Figure 20.—*Abies lasiocarpa/Carex geyeri* **habitat type. In this old-growth stand, there are only remnants of seral** *Pinus contorta* **present.**

Figure 21.—*Abies lasiocarpa/Carex geyeri* habitat type. Seral *Pinus contorta* and *Populus tremuloides* dominate the overstory of this stand.

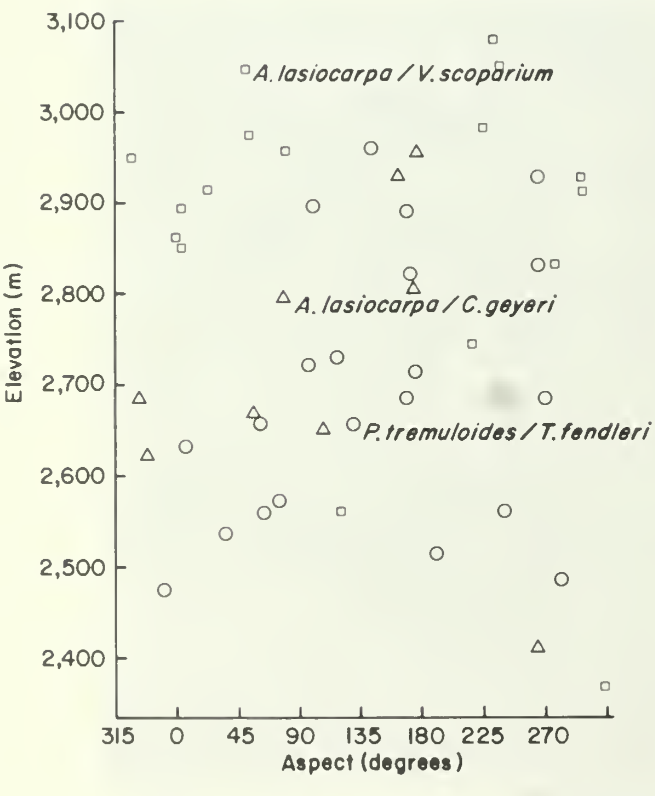

Figure 22.—Relationship of major habitat types to aspect and elevation on the Routt National Forest.

KEY TO THE FOREST HABITAT TYPES OF THE ROUTT NATIONAL FOREST

1. Conifers dominant and reproducing:

2. *Pinus flexilis* present; other conifers absent .... *PINUS FLEXILIS/ JUNIPERUS COMMUNIS* H. T.

2. Coniferous trees other than *Pinus flexilis* present and reproducing:

3. *Pinus contorta, Picea engelmannii,* and *Abies lasiocarpa* absent, or at least not reproducing. *Pseudotsuga menziesii* present and reproducing satisfactorily .... *PSEUDOTSUGA MENZIESII/ PACHISTIMA MYRSINITES* H. T.

3. *Pinus contorta, Picea engelmannii,* and *Abies lasiocarpa* present and may be reproducing; *Pseudotsuga* may be present but reproducing insufficiently to maintain its population:

4. *Pinus contorta* reproducing; no evidence of invasion by *Picea engelmannii* or *Abies lasiocarpa* .... *PINUS CONTORTA/ SHEPHERDIA CANADENSIS* H. T.

4. *Abies lasiocarpa* and/or *Picea engelmannii* dominant and reproducing. *Pinus contorta* and/or *Populus tremuloides* may be present but reproducing insufficiently to maintain population:

5. Undergrowth dominated by *Vaccinium scoparium* .... *ABIES LASIOCARPA/ VACCINIUM SCOPARIUM* H. T.

5. Undergrowth dominated by *Carex geyeri; Vaccinium scoparium* may be present but not dominant .... *ABIES LASIOCARPA/ CAREX GEYERI* H. T.

Conifers may be present but neither dominant nor reproducing suffciently to maintain their populations. Deciduous trees dominant and reproducing satisfactorily:

6. *Quercus gambellii* dominant. Other tree species absent or not dominant .... *QUERCUS GAMBELII/ SYMPHORICARPOS OREOPHILUS* H. T.

6. *Populus tremuloides* dominant; *Quercus gambelii* may also be present. Occasional conifer may also be present:

7. *Symphoricarpos oreophilus* dominant in undergrowth. *Amelanchier alnifolia* and *Prunus virginiana* may also be conspicuous .... *POPULUS TREMULOIDES/ SYMPHORICARPOS OREOPHILUS* H. T.

7. *Symphoricarpos oreophilus* may be present but not dominant in the undergrowth. *Amelanchier alnifolia* and *Prunus virginiana* absent or not abundant. Undergrowth characteristically a rich mixture of herbaceous species including *Thalictrum fendleri, Ligusticum porteri, Geranium richardsonii, Lathyrus leucanthus, Vicia americana, Bromus ciliatus*, and *Elymus glaucus:*

8. *Heracleum sphondyllium* the dominant species in the undergrowth .... *POPULUS TREMULOIDES/ HERACLEUM SPHONDYLLIUM* H. T.

8. *Heracleum sphondyllium* may be present but not dominant in the undergrowth:

9. *Veratrum tenuipetalum* dominant in the undergrowth .... *POPULUS TREMULOIDES/ VERATRUM TENUIPETALUM* H. T.

9. *Veratrum tenuipetalum* may be present but not dominant in the undergrowth:

10. *Pteridium aquilinum* dominant in the undergrowth .... *POPULUS TREMULOIDES/ PTERIDIUM AQUILINUM* H. T.

10. *Pteridium aquilinum* may be present but not dominant in the undergrowth ..... *POPULUS TREMULOIDES/ THALICTRUM FENDLERI* H. T.

The distribution and successional status of tree species in relation to habitat type are shown in figure 23.

DISCUSSION

Validity of Habitat Type Classification

This is one of a number of studies in the Rocky Mountain region to classify forests using the habitat type approach of Daubenmire and Daubenmire (1968). The validity of the habitat type classifications has been discussed by Daubenmire and Daubenmire (1968), Hoffman and Alexander (1976), and Pfister et al. (1977). The practical value of the habitat type classifications has only begun to be realized in areas of vegetation mapping, relation to tree growth, susceptibility to diseases, production of browse species for game animals, and in providing a framework within which to relate additional basic or applied biological studies.

The classification system, while using vegetation as the indicator of site potentials, draws together available related information on soil and climate. While initially using vegetation as the criterion of delimiting habitat types, this approach also takes a holistic view of units of land area. The older the stands observed, the more closely they approximate the potential (climax or near climax) of the landscape units studied (Daubenmire 1976).

This classification system utilizes both overstory and undergrowth vegetation in recognizing habitat types. In this study, the two major vegetation zones are dominated by *Populus tremuloides*, and *Abies lasiocarpa* and *Picea engelmannii.* It is apparent that the *Populus* zone on the Routt National Forest and elsewhere in Colorado is warmer and drier than the *Abies* zone. Edaphic factors are also more alike within than between zones.

The classification of habitat types recognizes climax tree species in an area; these are given primary consideration, and important seral species are noted. Undergrowth vegetation is then used to indicate habitat types within the zone where a given tree species is climax. Within the *Populus* zone of the Routt National Forest, five habitat types were recognized based on relatively few species. The *P. tremuloides/Thalictrum fendleri* and *P. tremuloides/Symphoricarpos oreophilus* habitat types are considered to be climatic climaxes. The *P. tremuloides/T. fendleri* habitat

Habitat type \ Species	*Pinus flexilis*	*Pseudotsuga Menziesii*	*Quercus gambelii*	*Populus tremuloides*	*Pinus contorta*	*Picea engelmannii*	*Abies lasiocarpa*
Pinus flexilis/Juniperus communis	C						
Pseudotsuga menziesii/Pachistima myrsinites		C	s	s			
Quercus gambelii/Symphoricarpos oreophilus			C				
Populus tremuloides/Symphoricarpos oreophilus			S	C			
Populus tremuloides/Heracleum sphondyllium				C			o
Populus tremuloides/Veratrum tenuipetalum				C		o	o
Populus tremuloides/Pteridium aquilinum				C			o
Populus tremuloides/Thalictrum fendleri				C	o	o	o
Pinus contorta/Shepherdia canadensis				o	C		o
Abies lasiocarpa/Vaccinium scoparium				s	S	C	C
Abies lasiocarpa/Carex geyeri				S	S	C	C

C = major climax species S = seral s = seral in some stands o = occasional

Figure 23.—Distribution of tree species through habitat types, showing dynamic status.

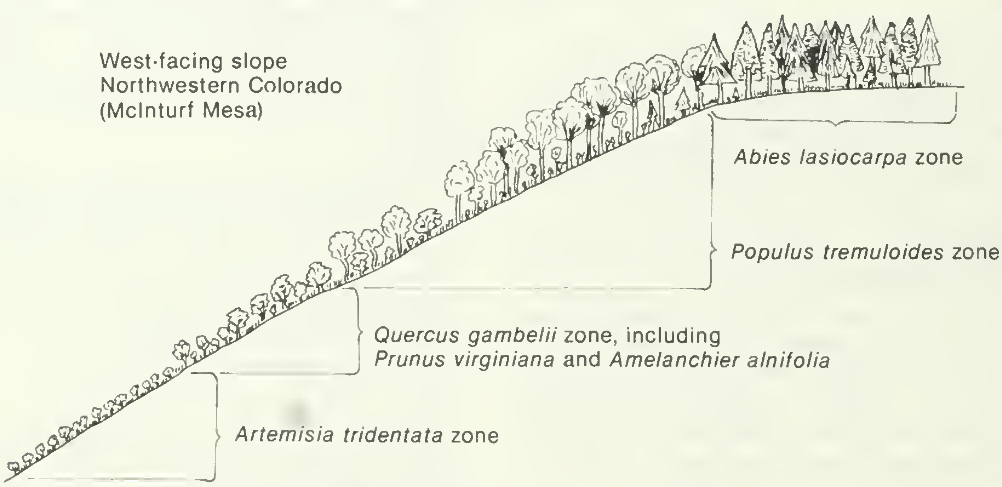

Figure 24.—An example of vegetation zonation on McInturf Mesa and above, Routt National Forest.

type occupies soils apparently developed through normal processes throughout most of the zone, and the *P. tremuloides/S. oreophilus* habitat type normally occupies soils developed in place at lower and drier edges of the zone. Throughout most of the *Populus*-dominated zone, there are restricted areas where combinations of edaphic and topographic characteristics allow *Heracleum sphondyllium*-, *Veratrum tenuipetalum*-, and *Pteridium aquilinum*-dominated undergrowth to establish under *Populus*. Although *P. tremuloides/T. fendleri* is the climatic climax throughout much of the *Populus* zone, undergrowth vegetation is expressed rather independently of the *P. tremuloides* overstory.

In the *Abies lasiocarpa* zone, the two habitat types, *Abies lasiocarpa/Vaccinium scoparium* and *Abies lasiocarpa/Carex geyeri*, are distinguished by differences in relatively few undergrowth species. However, the two habitat types also show some topographic and elevational differences. Additionally, *P. tremuloides* is an important seral species in the *A. lasiocarpa/C. geyeri* habitat type, but only a minor seral species in the *A. lasiocarpa/V. scoparium* habitat type.

Vegetation Zonation

An example of vegetation zonation in the Routt National Forest—McInturf Mesa and above—is shown in figure 24. *Pinus contorta* is not shown because of its restricted distribution as a climax species. *Pinus ponderosa* and *Pseudotsuga menziesii* were omitted because they are minor climax species in the Routt National Forest (fig. 25). The area depicted in figure 24 is typical in that *Artemisia tridentata*-dominated shrub-steppe is widely distributed at lower elevations. Shrub communities dominated by *Prunus virginiana* and *Amelanchier alnifolia* occur between the *Artemisia*-dominated vegetation, and the *Quercus gambelii*-dominated vegetation at higher elevations. In locations where neither the *Prunus/Amelanchier* and *Quercus* communities occur, *Artemisia* shrub-steppe extends to *Populus tremuloides*-dominated vegetation (fig. 26).

The absence of well defined *Pinus ponderosa* and *Pseudotsuga menziesii* zones over much of the area probably results from drought at low elevations and low temperatures at higher elevations. Despite Bates (1924) suggestion that *P. menziesii* may have occupied much of the lower elevations in the Routt National Forest, but was replaced by *Populus* following repeated fires, there are no data or field evidence available to corroborate this suggestion, even though there is evidence that fire played an important role in the establishment of *Populus* forests (fig. 27). Moreover, *Pseudotsuga menziesii* shows little tendency to establish in areas now occupied by *Populus tremuloides*. Nor are there relicts of *Pseudotsuga menziesii* in *Populus tremuloides* stands to suggest it was formerly present.

Populus tremuloides is a climax tree in five habitat types in the Routt National Forest. At its upper elevational limit, *Populus tremuloides* extends into the *Abies lasiocarpa* zone and there are numerous stands in which *Populus* is obviously seral to *Abies*. The subalpine forest, dominated by *A. lasiocarpa* and *Picea engelmannii* occurs from about 8,200 feet (2,500 m) to timberline.

Biotic Succession

The role of *Populus tremuloides* as a seral and/or climax species has been discussed at length by Baker (1925), Dixon (1935), Fetherolf (1917), Gardner (1905), Sampson (1925), and Youngblood (1979). Most investigators have agreed that *P. tremuloides* is an aggressive species on areas that have been burned, logged, or otherwise disturbed; it reproduces primarily by root suckers. There is less agreement on the stability of *P. tremuloides* once it is established. Data and observations from the present study suggest that both seral and climax stands of *P. tremuloides* occur in the Routt National Forest. Seral *Populus* stands are quite obvious where *Abies lasiocarpa* and *Picea engelmannii* are the climax species. In the *Pinus contorta/Shepherdia canadensis* habitat type, *Populus tremuloides* is only an occasional seral species. In *Abies*-dominated habitat types, either *Populus tremuloides* or *Pinus contorta* may become established first after disturbance or they may establish simultaneously. The availability of *Pinus* seed or *Populus* root sprouts determines which species initially becomes established.

Climax stands of *Populus tremuloides* show no clear evidence of successful conifer invasion. The presence of a limited number of coniferous seedlings in the undergrowth is insufficient evidence of succession. In addition, *Populus* usually has a stable population structure. The understory vegetation of the *Populus*-dominated habitat types is distinct, even though common species occur between *P. tremuloides*-dominated habitat types and other habitat types in the forest. Some soils differences exist between *Populus*-dominated and *Abies*-dominated habitat types. The oldest stand of climax *Populus*-dominated habitat types on the Routt National Forest was about 150 years old. If succession toward *Abies* and *Picea* forests is not evident in 150-year-old stands, they should be viewed and managed as climax forests.

Climax stands of *Pinus contorta* show no clear evidence of replacement by other conifers even though other seed sources are available. Moreover, climax *P. contorta* stands show a generally stable stand structure. The ability of *P. contorta* to remain dominant appears related to such topoedaphic factors as tolerance to intense solar radiation, nightly cold air accumulation and frost, and unstable and droughty soils.

In the *Abies lasiocarpa/Vaccinium scoparium* habitat type, *Populus tremuloides* is not an important seral species compared to *Pinus contorta*. In the *Abies lasiocarpa/Carex geyeri* habitat type, the reverse seems to be true. On the basis of observations made during this study, figure 28 is suggested as a working model of succession in *Abies*-dominated forests in the Routt National Forest. From the population structures of seral communities, it appears that any one of these three communities may become established and be succeeded by any one of the others before the *Abies*-dominated forest becomes established.

Species Richness

The median numbers of undergrowth species in stands of each habitat type are given in table 2. Starting at the lowest edge of the forest and moving upslope, ignoring all but apparent climatic climaxes, the maximum species richness is in the *Populus* zone (table 2). The relatively large number of undergrowth species in the *Abies lasiocarpa/Carex geyeri* habitat type reflects the large number of undergrowth species also common to the *Populus* zone. Tree species richness was greatest in *Abies*-dominated habitat types.

Species richness has also been reported for habitat types elsewhere in the Rockies. In the Wind River Mountains, it increased with increasing elevation (Reed 1969). In northern Idaho and eastern Washington, undergrowth species richness among climatic climaxes was greatest in mid-elevational habitat types dominated by *Pseudotsuga menziesii* and *Abies grandis*, and tree species richness was greatest in the *Abies lasiocarpa*-dominated habitat types (Daubenmire and Daubenmire 1968). In the Bighorn

Figure 25.—*Pinus ponderosa* is rare in the Routt National Forest. It is represented mainly by old, scattered individuals, but without evidence of reproduction.

Figure 26.—*Populus tremuloides* invading into adjacent *Artemisia tridentata*-dominated shrub-steppe.

Figure 27.—Mosaic of vegetation types on an east slope, Routt National Forest. Sharp ecotones separating coniferous forest from *Populus tremuloides* forest suggest that *Populus* may have become established after fire. Different stand structures of *Populus*-dominated forests suggest continued spreading or establishment of new clones. Young *Populus* forms a fringe around the lower edge of the forest.

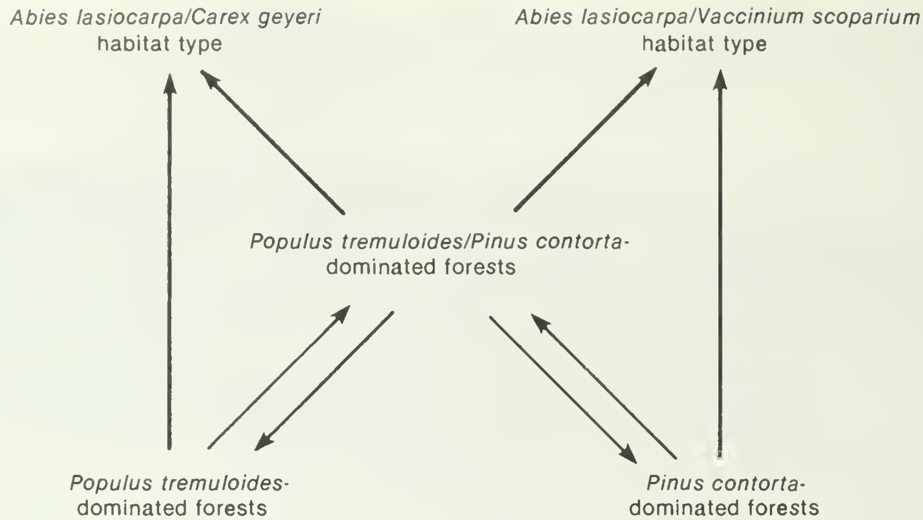

Figure 28.—Suggested succession in *Abies*-dominated forests in the Routt National Forest. The most apparent successional trends are shown by single arrows. Double arrows illustrate possible successional trends among the three different seral communities that occur—*Populus tremuloides, Pinus contorta,* and *Populus tremuloides/Pinus contorta.*

Table 2.—Species of undergrowth vegetation in habitat types of the Routt National Forest

Habitat type	Median number[1] of undergrowth species	Number of stands studied
Pinus flexilis/ Juniperus communis	17	3
Pseudotsuga menziesii/ Pachistima myrsinites	8	2
Quercus gambelii/ Symphoricarpos oreophilus	19	3
Populus tremuloides/ Symphoricarpos oreophilus	25	7
Populus tremuloides/ Thalictrum fendleri	27	26
Populus tremuloides/ Heracleum sphondyllium	23	4
Populus tremuloides/ Veratrum tenuipetalum	35	3
Populus tremuloides/ Pteridium aquilinum	30	7
Pinus contorta/ Shepherdia canadensis	15	6
Abies lasiocarpa/ Vaccinium scoparium	15	25
Abies lasiocarpa/ Carex geyeri	20	11

[1]*Based on 125 m^2 per stand.*

Mountains, greatest undergrowth species richness was in low and high elevation habitat types dominated by *Pinus ponderosa* and *Abies lasiocarpa*, respectively (Hoffman and Alexander 1976).

Further Studies in Relation to the Habitat Types

The present study was to provide a basic classification of the forest habitat types in the Routt National Forest. There are numerous areas of research which logically follow the present study.

The production of undergrowth vegetation in relation to habitat types needs to be examined. Ellison and Houston (1958), working in Utah, suggested that production of vegetation under *Populus tremuloides* could be used as an indicator of forage production and, therefore, range condition. In the Routt National Forest, both cattle and sheep utilize, sometimes quite heavily, vegetation under *Populus*. It would be valuable to know the relationship between habitat types and potential undergrowth productivity.

The growth rates of important timber trees may correlate with habitat types similar to the relationship of growth rates of *Pinus ponderosa* and the habitat types in the northern Rocky Mountains described by Daubenmire (1961).

Numerous fungi attack *Populus tremuloides* in Colorado (Juzwik et al. 1978). Some *Populus* habitat types may be more susceptible to various species of fungi than others are. In northern Idaho and eastern Washington, *Arceuthobium* infects *Pinus ponderosa* in the *P. ponderosa/Agropyron spicatum* and *P. ponderosa/Purshia tridentata* habitat types, but not in other habitat types dominated by *P. ponderosa* (Daubenmire 1961). There is a possibility that susceptibility of *Picea engelmannii* to insect infestation may be correlated with habitat types in Colorado (Shepherd 1959).

The relationship of forest habitat types and their successional stages to wildlife management also needs further research.

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APPENDIX

Table A-1.—Tree population structures for each habitat type. Numbers of trees listed are based on sample plot data of 375 m² per stand

Habitat type and species	Stands sampled	Mean basal area	Diameter (b.h.) classes in dm 0-1 <0.5	>0.5	1-2	2-3	3-4	4-5	5-6	6-7	7-8	Over 8
	number	*m²/ha*	*number of trees*									
Pinus flexilis/Juniperus communis	3	18.4										
Pinus flexilis			3	7	15	3	1	([1])	0	([1])	0	0
Quercus gambelii/Symphoricarpos oreophilus												
Quercus gambelii	3	23.2	538	53	32	1	([1])	0	0	0	0	0
Pseudotsuga menziesii/ Pachistima myrsinites	2	38.1										
Pseudotsuga menziesii			217	17	22	8	4	0	0	0	0	0
Populus tremuloides			38	1	2	0	0	0	0	0	0	0
Abies lasiocarpa			0	0	([1])	0	([1])	0	0	0	0	0
Quercus gambelii			4	2	2	([1])	0	0	0	0	0	0
Populus tremuloides/ Symphoricarpos oreophilus	7	24.4										
Populus tremuloides			46	14	27	10	([1])	0	([1])	0	0	0
Quercus gambelii			25	6	3	([1])	([1])	0	0	0	0	0
Populus tremuloides/Thalictrum fendleri	26	45.6										
Populus tremuloides			220	15	24	12	4	1	([1])	([1])	0	0
Pinus contorta			0	0	([1])	([1])	([1])	0	0	0	0	0
Abies lasiocarpa			7	([1])	([1])	([1])	([1])	0	0	0	0	0
Picea engelmannii			([1])	0	0	([1])	([1])	0	0	0	0	0
Populus tremuloides/Heracleum sphondyllium	4	41.2										
Populus tremuloides			301	7	8	16	5	([1])	([1])	0	0	0
Abies lasiocarpa			([1])	([1])	0	([1])	0	0	0	0	0	0
Populus tremuloides/Veratrum tenuipetalum	3	42.9										
Populus tremuloides			49	12	17	14	1	2	([1])	0	0	0
Pinus contorta			([1])	0	0	0	0	0	0	0	0	0
Abies lasiocarpa			22	0	0	0	0	0	0	0	0	0
Picea engelmannii			5	0	0	0	0	0	0	0	0	0
Populus tremuloides/Pteridium aquilinum	7	29.6										
Populus tremuloides			37	9	16	9	2	([1])	0	0	0	0
Abies lasiocarpa			6	([1])	([1])	0	0	0	0	0	0	0
Pinus contorta/Shepherdia canadensis	6	42.3										
Pinus contorta			39	13	27	11	2	([1])	0	0	0	0
Populus tremuloides			([1])	0	0	0	0	0	0	0	0	0
Abies lasiocarpa			14	0	0	0	0	0	0	0	0	0
Abies lasiocarpa/Vaccinium scoparium	25	49.8										
Abies lasiocarpa			182	6	6	2	([1])	([1])	([1])	0	0	0
Picea engelmannii			32	3	3	2	([1])	([1])	([1])	([1])	0	([1])
Pinus contorta			5	3	8	7	2	([1])	([1])	([1])	0	0
Populus tremuloides			2	([1])	([1])	0	0	0	0	0	0	0
Abies lasiocarpa/Carex geyeri	11	52.6										
Abies lasiocarpa			170	3	2	([1])	([1])	([1])	([1])	0	0	0
Picea engelmannii			51	([1])	2	([1])	([1])	([1])	([1])	0	0	([1])
Pinus contorta			1	3	5	5	4	([1])	([1])	0	0	0
Populus tremuloides			35	7	17	6	([1])	0	0	0	0	0

[1]*Species with less than 1.0 per d.b.h. class.*

Table A-2.—Location, topographic position, coverage (percent), and frequency (percent) of undergrowth species in stands of the *Pinus flexilis/Juniperus communis* habitat type

	Stand number		
	66	95	98
Location:			
Section	17	17	3
Township	11N	11N	9N
Range	81W	81W	81W
Topographic position:			
Slope	23%	30%	32%
Aspect	242°	238°	81°
Elevation (m)	2,609	2,615	2,530
	Coverage/Frequency		
Shrubs			
Artemisia tridentata	—	([1])/4	([1])/6
Cercocarpus montanus	—	—	0.6/12
Juniperus communis	7.6/16	4.9/8	5.2/14
Pinus flexilis	0.6/4	5.2/16	3.3/10
Purshia tridentata	—	—	([1])/4
Rhus trilobata	([1])/2	—	—
Ribes cereum	([1])/6	0.5/12	—
Sedum lanceolatum	—	([1])/6	([1])/8
Symphoricarpos oreophilus	([1])/2	—	—
Graminoids			
Agropyron trachycaulum	([1])/4	—	—
Festuca idahoensis	([1])/6	0.5/12	0.7/8
Koeleria cristata	([1])/4	—	([1])/2
Leucopoa kingii	1.2/8	0.6/4	1.6/12
Poa agassizensis	—	([1])/2	—
Poa nervosa	—	—	([1])/2
Stipa viridula	—	([1])/6	([1])/2
Stipa comata	([1])/2	—	([1])/4
Forbs			
Antennaria rosea	([1])/6	—	([1])/4
Arenaria congesta	([1])/4	0.5/16	—
Crepis acuminata	0.6/4	—	—
Drymocallis fissa	—	([1])/8	—
Erigeron flagellaris	0.6/4	—	—
Eriogonum umbellatum	—	([1])/4	0.8/8
Harbouria trachypleura	([1])/4	0.7/8	—
Lewisia rediviva	([1])/4	—	—
Phlox multiflora	—	([1])/6	([1])/8
Potentilla hippiana	([1])/4	—	—
Senecio fendleri	([1])/4	—	—
Zigadenus elegans	—	0.6/4	—
Lichens and mosses[2]	3.4/4	6.9/28	0.7/16
Total species	18	17	16
Total coverage (percent)	15.6	21.3	13.4

[1]*Coverage of less than 0.5%.*
[2]*Lichens and mosses are considered as one additional species.*

Table A-3.—Location, topographic position, coverage (percent), and frequency (percent) of undergrowth species in stands of *Pseudotsuga menziesii/Pachistima myrsinites* habitat type

	Stand number	
	94	99
Location:		
Section	35	24
Township	9N	6N
Range	85W	84W
Topographic position:		
Slope	42%	37%
Aspect	336°	348°
Elevation (m)	2,573	2,164
	Coverage/Frequency	
Shrubs		
Acer glabrum	11/40	5.6/28
Amelanchier alnifolia	2.8/16	1.2/12
Ceanothus velutinus	—	0.5/10
Mahonia repens	1.5/4	—
Moneses uniflora	—	([1])/6
Pachistima myrsinites	17/88	21/72
Populus tremuloides	0.6/4	—
Prunus virginiana melanocarpa	—	([1])/4
Pseudotsuga menziesii	1.1/18	0.6/12
Quercus gambelii	—	1.8/14
Ramischia secunda	([1])/8	—
Rosa woodsii	1.9/20	—
Sorbus scopulina	—	2.2/14
Symphoricarpos oreophilus	2.2/12	3.7/20
Vaccinium myrtillus	4.4/24	0.6/14
Vaccinium scoparium	—	([1])/8
Graminoids		
Bromus ciliatus	0.6/4	—
Calamagrostis rubescens	—	2.2/26
Carex geyeri	([1])/4	—
Poa nervosa	—	([1])/2
Forbs		
Arnica cordifolia	2.6/28	1.0/12
Aster engelmannii	1.5/4	1.2/6
Disporum trachycaulum	([1])/12	—
Epilobium angustifolium	0.6/4	0.5/6
Fragaria sp.	([1])/4	—
Lathyrus leucanthus	0.8/10	0.5/8
Osmorhiza sp.	([1])/12	0.6/18
Smilacina racemosa	0.7/8	—
Stellaria jamesiana	—	([1])/10

[1]*Coverage of less than 0.5%.*

Table A-4.—Location, topographic position, coverage (percent) and frequency (percent) of undergrowth species in stands of *Quercus gambelii/Symphoricarpos oreophilus* and *Populus tremuloides/Symphoricarpos oreophilus* habitat types

	Stand number									
	Quercus/ Symphoricarpos			*Populus/Symphoricarpos*						
	90	84	80	11	17	65	75	81	88	92
Location:										
Section	31	20	32	20	22	12	1	29	33	29
Township	9N	4N	8N	8N	3N	3N	9N	8N	7N	9N
Range	89W	85W	87W	87W	86W	87W	84W	87W	84W	89W
Topographic position:										
Slope	10%	35%	7%	—	30%	10%	32%	10%	18%	15%
Aspect	142°	296°	194°	—	61°	346°	152°	66°	124°	144°
	Coverage/Frequency									
Shrubs										
Abies lasiocarpa	—	—	—	—	(1)/2	—	—	—	—	—
Amelanchier alnifolia	2/20	11/24	(1)/4	4/24	25/78	0.7/6	1.8/6	22/52	11/60	0.6/4
Artemisia tridentata	—	0.6/4	(1)/2	—	—	—	—	—	—	—
Juniperus communis	(1)/4	—	—	—	—	—	—	—	—	—
Mahonia repens	—	—	—	—	1.1/6	—	5.7/40	0.6/4	2/40	—
Pachistima myrsinites	—	0.7/8	—	—	—	—	0.9/6	—	—	—
Populus tremuloides	—	—	—	—	—	—	—	(1)/2	—	(1)/4
Prunus virginiana	2.2/12	18/56	(1)/2	(1)/2	—	—	6.5/30	1.2/8	1.9/16	—
Quercus gambelii	5.4/40	6.1/32	17/36	—	—	—	—	(1)/4	(1)/4	2.2/12
Ribes montigenum	—	—	—	–10	10/30	9.5/30	—	—	—	—
Rosa woodsii	—	0.7/8	—	(1)/4	1.4/6	—	(1)/2	2.1/8	1.6/8	11/36
Symphoricarpos oreophilus	22/72	50/92	4/24	40/82	10/44	30/76	29/62	11/28	16/60	(1)/12
Graminoids										
Agropyron inerme	—	—	0.9/8	—	—	—	—	—	—	—
Agropyron smithii	—	—	(1)/8	—	—	—	—	—	—	—
Agropyron trachycaulum	—	1.4/16	1/10	—	—	—	—	—	—	—
Bromus anomalus	—	1.2/18	—	—	—	2/8	—	(1)/2	—	—
Bromus ciliatus	—	4.2/24	7.6/32	2.4/26	14/56	12/60	1.1/14	3.6/28	1.4/16	1/20
Carex geyeri	44/92	3.7/16	—	—	3.2/12	1.6/8	44/94	1.2/8	10/40	25/84
Calamagrostis canadensis	—	12/56	—	—	—	(1)/2	—	—	—	0.9/16
Elymus glaucus	0.9/16	—	—	13/76	14/56	5.2/42	6.3/30	9.1/52	7/44	4.1/44
Melica spectabilis	—	—	(1)/4	—	—	1.5/18	0.9/16	(1)/4	1.5/20	—
Poa interior	1.8/16	0.6/4	2.6/64	10/68	(1)/4	5.6/36	—	—	—	2.6/14
Poa pratensis	3.6/28	—	28/72	18/56	1.3/12	9/48	—	(1)/4	—	6.2/60
Stipa lettermanii	—	1.2/8	—	—	—	—	—	—	—	—
Forbs										
Achillea millefolium	1.6/8	2.9/56	7.7/56	3.6/28	(1)/4	3.4/24	2.5/28	2.7/32	1.3/12	0.6/24
Actaea rubra	—	—	—	—	2.7/12	1.5/4	—	1.2/8	—	—
Agastache urticifolia	—	0.6/4	—	1.8/22	—	2.1/8	0.9/6	3.5/40	3/40	1.7/28
Antennaria rosea	—	—	—	—	—	—	0.6/4	—	—	—
Aquilegia coerulea	—	—	—	—	0.5/8	4.6/22	—	—	0.7/8	—
Arnica parryi	—	(1)/4	—	—	—	—	1.1/4	2.2/12	—	—
Aster engelmannii	—	—	—	—	—	(1)/2	0.6/4	0.6/4	4.4/24	—
Castilleja sulphurea	—	—	—	—	—	—	0.9/8	—	—	—
Cirsium sp.	0.7/8	—	—	—	—	(1)/2	5.2/26	—	1.8/12	—
Corallorhiza trifida	—	—	—	—	(1)/2	—	—	—	—	—
Delphinium barbeyi	—	—	—	1.1/6	—	—	—	—	—	(1)/4
Erigeron elatior	0.2/8	2.5/20	(1)/2	—	—	1.9/16	—	—	(1)/4	0.7/8
Erigeron speciosus	—	—	—	—	—	(1)/2	—	—	(1)/2	(1)/4
Eriogonum umbellatum	—	6.9/28	—	—	—	—	—	—	—	—
Fragaria sp.	—	—	—	—	(1)/4	(1)/2	—	—	—	—
Galium boreale	—	5.5/44	—	(1)/6	(1)/2	(1)/6	0.7/18	2.7/48	2.1/24	(1)/12
Geranium richardsonii and *caespitosum*	(1)/4	—	—	4.7/22	7/48	1.6/12	—	(1)/8	1.3/12	—
Heliomeris multiflora	—	—	—	—	—	—	—	—	(1)/12	—
Heracleum sphondyllium	—	—	—	—	—	(1)/2	—	—	—	—
Hydrophyllum capitatum	—	—	—	—	—	13/50	—	—	—	(1)/4
Lathyrus leucanthus	2.6/28	—	—	1.2/10	3.1/16	1.1/6	8.9/46	2.4/16	0.6/4	9.6/56
Ligusticum porteri	—	—	—	(1)/2	—	2.2/18	—	8.4/32	—	—
Lupinus argenteus ssp. *rubricaulis*	0.6/4	—	—	—	—	(1)/2	—	(1)/2	—	—
Osmorhiza sp.	(1)/2	—	—	0.5/8	17/84	11/52	7.3/40	7/44	1.4/16	7/48
Senecio crassulus	—	—	—	—	—	—	—	(1)/2	(1)/4	—
Smilacina racemosa	—	—	—	—	0.5/8	—	—	0.6/4	—	(1)/4
Stellaria jamesiana	—	1.3/12	(1)/8	(1)/2	—	1.1/16	—	3.2/48	(1)/8	—
Taraxacum sp.	—	—	—	0.6/12	4.9/32	1.2/18	0.6/6	—	(1)/4	—
Thalictrum fendleri	—	2.7/12	—	10/54	0.7/6	8.9/34	26/62	46/96	29/84	15/72
Thlaspi montanum	—	0.7/8	(1)/4	—	—	(1)/10	(1)/6	—	—	—
Thermopsis montana	—	—	—	—	—	—	—	0.6/4	—	—
Valeriana occidentalis	—	—	—	(1)/4	(1)/2	4.9/30	—	—	8.1/36	—
Vicia americana	0.7/8	(1)/4	(1)/4	1.3/10	0.6/4	4.1/18	8.6/44	9.9/48	2.5/20	—
Viola nuttallii	0.6/24	—	—	—	—	1.2/4	(1)/2	(1)/8	—	—
Wyethia amplexicaulis	4/24	—	4.4/24	—	—	—	—	—	—	—

[1]*Coverage of less than 0.5%.*

Table A-5.—Location, topographic position, coverage (percent), and frequency (percent) of undergrowth species in stands of the *Populus tremuloides/Thalictrum fendleri* habitat type

	Stand number																									
	39	6	21	22	23	26	42	69	74	27	35	91	12	38	78	79	9	10	13	14	67	70	78	19	77	72
Location: Section	10	20	15	30	31	14	29	23	21	31	15	20	23	22	27	10	32	33	9	2	17	25	6	36	36	21
Township	5N	3N	1N	3N	3N	2N	3N	3N	2N	10N	9N	10N	10N	9N	10N	10N	11N	11N	11N	10N	11N	10N	9N	7N	7N	7N
Range	80W	87W	86W	86W	86W	88W	87W	86W	88W	87W	89W	88W	87W	87W	87W	87W	85W	85W	85W	86W	85W	84W	83W	83W	84W	82W
Topographic position:																										
Slope	19%	25%	—	—	—	20%	40%	15%	19%	—	28%	14%	7%	5%	11%	12%	—	24%	30%	33%	9%	6%	20%	12%	29%	15%
Aspect	286°	171°	—	—	—	96°	261°	100°	141°	—	116°	238°	76°	352°	66°	38°	—	131°	6°	176°	280°	172°	190°	171°	270°	58°
Elevation (m)	2,829	2,819	2,576	2,737	2,835	2,719	2,926	2,896	2,957	2,804	2,731	2,560	2,573	2,475	2,560	2,536	2,682	2,658	2,633	2,713	2,487	2,682	2,512	2,890	2,682	2,652
	Coverage/Frequency																									
Shrubs																										
Abies lasiocarpa	—	—	—	—	5.1/12	—	—	3.1/10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Amelanchier alnifolia	—	—	—	—	—	—	—	—	—	—	1.4/8	—	—	—	—	—	—	—	—	—	0.8/2	—	—	—	0.8/2	—
Mahonia repens	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.4/36	—	—	0.6/4	—	1 1/4	—	—	—
Pachistima myrsinites	—	(')/6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(')/2	—	—	—	—	—	—	—	—
Populus tremuloides	—	—	6.2/28	5.2/22	3.9/14	—	0.9/6	3.7/22	—	—	—	0.5/10	—	4/38	—	1.7/8	—	—	—	—	—	1.2/8	—	—	—	(')/4
Prunus virginiana	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1 7/2	—	—	—	—	—
Ribes montigenum	—	—	(')/2	—	—	—	—	—	(')/2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Rosa woodsii	—	1.8/14	—	4/30	—	—	—	2.1/14	—	—	—	(')/4	—	—	—	—	—	(')/4	—	—	2.1/16	(')/2	—	—	—	2.2/12
Rubus parviflorus	—	—	—	—	(')/4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	24/48	—
Sambucus racemosa	—	—	—	—	—	—	—	—	—	—	—	—	—	0.8/2	—	—	—	—	—	—	—	—	—	—	—	—
Sorbus scopulina	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.6/4	—
Symphoricarpos oreophilus	—	(')/6	—	4.5/10	—	—	6/18	—	—	—	—	—	—	2.5/4	(')/2	(')/2	—	—	—	—	2/16	—	12/36	—	—	6.6/22
Vaccinium myrtillus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6/20	—
Graminoids																										
Agropyron elongatum	(')/2	—	—	(')/2	—	—	(')/4	—	—	—	—	—	—	—	—	—	—	—	—	—	(')/2	—	0.6/4	—	—	—
Agropyron inerme	—	—	(')/2	—	—	—	—	(')/4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.6/6	—	—
Agropyron trachycaulum	—	—	—	—	(')/2	—	—	—	—	—	—	(')/2	—	—	(')/2	—	0.6/4	—	—	—	—	—	—	—	—	—
Bromus anomalus	—	1.2/14	—	—	(')/8	5.2/38	—	0.8/16	0.6/10	2/22	2.3/28	0.6/14	—	0.8/12	—	—	0.4/10	—	(')/6	1.2/34	(')/4	0.8/14	—	5.2/24	—	—
Bromus ciliata	11/62	5/28	3.8/20	9/58	4.4/22	21/86	5.1/30	20/80	(')/4	16/54	1.3/22	14/86	—	8.6/48	5/24	2/18	11/52	—	—	3.6/28	7.3/42	27/92	4.6/28	16/74	—	3.5/22
Calamagrostis canadensis	(')/4	—	—	—	—	—	—	—	—	—	(')/2	—	—	—	—	—	—	—	—	—	—	—	—	(')/6	—	—
Calamagrostis rubescens	—	—	—	—	—	—	—	—	—	—	—	—	2.6/24	—	—	—	—	38/78	30/66	1.5/4	—	—	—	—	—	—
Carex geyeri	22/62	42/94	20/58	29/80	—	(')/2	9.2/26	17/58	—	(')/2	25/72	2.8/6	13/62	—	—	—	—	1.8/14	(')/8	—	3.0/22	—	—	—	20/68	48/100
Carex hoodii	—	—	—	—	—	(')/2	—	—	—	—	(')/2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Carex raynoldsii	—	—	—	—	—	—	(')/4	—	—	—	—	—	1.4/16	—	—	—	—	—	(')/4	—	—	—	—	—	—	—
Carex sp.	—	—	—	(')/2	—	—	—	—	(')/2	(')/4	—	—	—	—	—	—	—	—	(')/2	—	(')/2	—	—	—	—	—
Elymus glaucus	(')/4	10/46	1.4/6	6.4/42	20/78	20/60	6.2/36	0.8/4	17/68	7.1/32	21/76	11/70	12/64	35/88	16/80	11/68	3.2/32	1/18	26/96	21/98	17/74	(')/2	9.9/64	8.1/56	11/46	1.6/12
Melica spectabilis	—	—	—	—	—	—	(')/2	(')/2	0.7/16	1.7/10	(')/2	—	(')/2	—	2 4/28	0.9/16	—	—	—	(')/4	1/10	7.1/46	1.7/18	(')/6	—	(')/4
Phleum pratense	—	—	—	—	—	(')/2	—	(')/2	—	—	—	0.6/4	—	—	1.4/8	1.3/12	0.8/20	—	—	—	2.1/8	(')/2	1.6/12	—	—	—
Poa canbyi	3.2/14	—	—	—	—	(')/6	—	—	0.8/10	—	—	—	—	—	—	1.2/16	—	—	—	(')/2	—	—	—	—	—	—
Poa interior	0.6/10	—	1.2/14	—	6.6/48	—	0.6/6	0.8/4	2.2/18	—	—	—	0.9/16	—	(')/4	—	2.5/30	—	—	3.5/36	4 2/30	—	—	1.5/22	—	—
Poa leptocoma	—	(')/2	—	—	—	(')/8	—	—	—	3.8/38	—	—	(')/4	—	—	—	0.8/14	—	—	0.8/10	—	0.6/8	—	—	—	—
Poa nevadensis	—	—	0.6/12	2.4/30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.8/28	—	0.5/8	—	—
Poa pratensis	—	—	14/48	4.3/28	—	—	—	—	—	(')/6	(')/2	—	3.7/34	4.4/20	—	—	—	6/30	5.2/28	—	—	6.7/46	—	1.1/20	—	—
Trisetum spicatum	—	—	—	—	—	—	—	—	—	(')/2	—	—	—	—	—	—	—	—	—	—	—	—	—	(')/4	—	—
Forbs																										
Achillea millefolium	—	0.8/10	(')/2	0.8/10	—	(')/2	2.8/32	1.3/20	—	—	0.6/14	(')/12	4.7/42	—	7.1/40	4.2/22	8.9/46	—	0.5/8	—	3.1/24	(')/4	3.5/24	—	—	9.6/58
Aconitum columbianum	—	—	—	—	3.4/28	2.1/18	—	(')/4	—	(')/2	0.5/8	—	—	—	0.8/10	—	—	(')/4	—	—	—	1.1/6	1.8/8	—	—	(')/2
Actaea rubra	2.2/4	—	—	—	(')/2	—	(')/4	—	—	—	—	—	—	—	—	—	—	—	—	—	(')/4	—	—	—	—	—
Agastache urticifolia	—	—	—	—	—	3.3/16	6.2/36	—	—	(')/4	—	—	—	—	1.1/12	—	—	—	—	(')/2	0.8/10	2.5/20	3.9/26	—	—	—
Androsace septentrionalis puberulenta	—	—	—	(')/2	—	(')/2	(')/12	—	1.9/16	0.8/10	—	—	—	—	0.3/2	—	(')/2	—	—	—	—	(')/4	(')/2	1.3/12	—	—

Aquilegia caerulea	—	—	1.1/12	—	—	—	([1])/2	—	([1])/2	3/14	—	—	—	—	—	—	—	—	0.5/10	—	([1])/2	0.6/4	6/26	—	1.3/2	—
Arabis drummondii	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	([1])/2	—	—	—	—
Arnica cordifolia	—	—	3.6/18	3.9/14	—	—	—	—	—	—	1/18	—	—	—	—	—	([1])/2	18/80	52/100	—	4.8/18	—	—	—	2/10	22/66
Arnica parryi	—	—	—	—	([1])/4	—	—	—	—	—	—	—	—	—	0.9/6	—	—	([1])/4	—	—	—	—	7.2/28	—	—	—
Aster engelmannii	—	—	—	1.4/16	—	2.8/16	4/14	([1])/4	4.5/26	2.1/16	11/66	([1])/4	—	([1])/2	8.6/42	([1])/2	—	—	2.4/24	—	—	([1])/2	1.7/8	—	15/70	0.6/14
Castilleja sulphurea	—	—	—	([1])/2	—	—	—	8.1/44	—	—	—	—	—	—	—	—	—	([1])/2	—	—	—	—	—	—	—	0.6/12
Chenopodium atrovirens	—	—	—	—	—	1.7/10	1/12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cirsium sp.	—	—	0.7/6	1.3/12	—	—	—	2.3/12	3.9/20	—	—	1/8	—	—	([1])/2	—	—	—	—	—	—	—	2.1/14	—	—	—
Collomia linearis	—	—	—	—	—	—	0.6/12	—	—	—	—	—	([1])/2	—	—	—	—	—	—	—	—	—	([1])/2	—	—	—
Delphinium barbeyi	([1])/2	—	—	—	12/50	23/54	([1])/2	—	6.6/26	7.1/18	—	2.5/28	—	4.7/24	4.2/10	1.2/10	([1])/2	—	—	—	1.4/18	—	—	—	—	—
Delphinium nelsonii	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.6/14	7.8/26	([1])/2	—	—
Descurainia californica	—	—	—	—	—	1.3/12	1.5/10	—	—	([1])/4	—	—	([1])/2	—	([1])/2	—	—	—	—	—	—	—	—	—	—	—
Epilobium angustifolium	1.1/12	—	—	([1])/2	—	—	—	—	—	—	([1])/2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Erigeron elatior	—	0.7/8	—	—	([1])/2	1.7/8	1.6/10	1.2/10	2.9/10	—	—	([1])/2	—	—	3.2/20	—	—	—	—	1/8	—	2/20	5.8/24	5.7/36	([1])/6	([1])/2
Erigeron speciosus	—	—	—	([1])/4	—	—	—	—	—	0.7/8	—	([1])/6	—	([1])/4	—	—	—	0.5/6	—	—	—	—	—	—	([1])/2	—
Fragaria sp.	—	—	([1])/12	1.2/16	0.5/8	—	—	19/86	—	—	0.7/8	4.9/64	1.3/30	0.9/16	([1])/6	14/66	1.1/12	2.2/12	—	—	3.4/36	—	5.1/48	—	—	—
Galium aparine	—	—	—	—	0.6/4	—	—	—	—	—	—	—	—	([1])/2	—	—	—	—	—	—	—	—	—	—	—	—
Galium boreale	([1])/10	1.0/10	1.4/14	4.2/38	1.8/30	—	—	—	3.6/44	—	1.3/20	3/40	0.5/8	0.9/6	—	—	([1])/2	—	—	—	—	7.8/56	([1])/6	—	—	([1])/2
Geranium nervosum	—	—	—	—	—	([1])/4	—	—	—	—	—	—	2.4/14	—	—	([1])/2	—	—	1.6/6	—	0.8/10	—	—	—	1.1/6	—
Geranium richardsonii	4/30	45/98	—	—	8.6/52	6.1/24	([1])/6	—	16/44	10/52	([1])/6	11/78	6.6/44	3.2/32	7.2/54	13/68	5.6/24	—	5.2/34	8.5/44	10/78	5.2/18	5.4/34	5.1/14	—	—
Geum allepicum	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.5/10	—	—	—	—	—	—	—	—	—
Helenium hoopesii	—	—	—	—	—	—	3.6/10	—	—	—	—	—	—	—	—	—	—	—	0.6/4	—	—	—	—	—	—	([1])/2
Heliomeris multiflora	—	—	—	0.8/6	—	([1])/4	0.8/2	—	—	—	—	—	—	—	—	([1])/2	—	—	—	—	—	—	—	4.8/32	—	—
Heracleum sphondyllium	—	—	—	—	1.3/14	—	—	—	—	12/32	—	—	—	1.8/14	([1])/2	0.7/8	—	—	—	13/34	—	—	([1])/2	—	—	—
Hydrophyllum capitatum	4.4/30	—	—	—	([1])/4	6.1/32	—	—	22/64	—	—	—	—	—	—	—	—	—	—	—	—	5.5/34	([1])/4	([1])/2	—	—
Lathyrus leucanthus	8.5/42	16/64	0.7/6	0.7/8	—	2.3/12	7.3/40	34/92	7.2/38	0.7/6	2.9/16	4.6/26	6.3/36	—	1.2/8	0.6/10	19/62	16/64	9.8/64	1.2/8	2/20	13/64	1.4/6	8.1/50	19/64	—
Ligusticum porteri	—	5/20	38/86	—	13/50	18/56	7.2/20	—	41/76	36/72	18/40	17/56	3.5/14	20/44	29/70	12/36	—	—	—	—	23/58	2.3/6	2.3/6	—	34/86	18/44
Lupinus argenteus rubricaulis	—	([1])/2	—	3.1/24	3.1/8	—	—	5.3/44	—	—	2.8/16	([1])/2	([1])/4	—	3.1/16	—	5.6/30	—	—	—	—	3.1/28	3.1/24	4.4/30	([1])/8	([1])/2
Mertensia ciliata	—	—	—	—	([1])/8	—	—	—	0.8/4	—	—	—	—	([1])/2	—	—	—	—	—	—	—	—	—	—	—	—
Nemophila breviflora	—	—	—	—	—	—	—	—	4.3/26	0.5/18	—	—	—	—	—	—	1.9/16	—	—	—	([1])/2	5/32	—	—	—	—
Osmorhiza sp.	11/52	5.3/30	([1])/2	1.4/14	1.1/22	2/50	11/40	—	5.3/14	3.7/23	7.3/40	11/44	1.3/10	7/46	12/36	5.5/30	([1])/4	—	([1])/2	11/42	8.8/34	6.1/30	5.4/16	0.8/4	([1])/4	—
Pedicularis procera	—	—	—	—	0.6/4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Penstemon whippleanus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	([1])/2	—	—
Polygonum douglasii latifolium	—	—	—	—	—	—	3.1/46	—	([1])/2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Potentilla arguta	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	([1])/4	—	—	—	—	—	—	—	([1])/2
Potentilla gracilis	—	—	—	—	—	—	—	—	—	—	—	([1])/2	([1])/2	—	([1])/2	—	—	—	—	—	([1])/4	—	1.9/16	—	—	—
Potentilla quinquefolia	—	—	—	—	—	—	—	0.7/6	—	—	—	([1])/2	—	—	—	—	—	([1])/2	—	—	([1])/4	—	—	—	([1])/4	—
Potentilla norvegica	—	([1])/2	—	—	—	—	—	—	—	—	—	—	—	—	—	([1])/4	—	—	—	—	—	—	—	1.8/20	—	—
Pteridium aquilinum	—	([1])/4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ranunculus inamoenus	—	—	—	—	—	—	—	—	—	([1])/2	—	—	—	—	—	—	([1])/4	—	([1])/8	—	1/10	—	1.2/16	—	—	—
Ranunculus uncinatus parviflorus	—	—	—	—	—	—	—	—	([1])/6	([1])/2	—	—	2.3/22	—	2/20	1.9/26	([1])/12	—	—	0.5/8	—	3.7/38	([1])/2	([1])/2	—	—
Senecio crassulus	—	—	—	—	—	—	—	1.1/4	([1])/2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	([1])/2
Senecio serra	17/56	—	—	—	—	1.5/10	([1])/4	1.5/10	2.2/18	4.8/20	([1])/2	—	—	2.3/14	—	—	—	—	—	0.5/8	—	2.2/12	0.8/2	—	—	—
Silene menziesii	([1])/4	([1])/2	—	—	—	4/40	—	([1])/4	—	1.4/14	—	—	—	—	—	—	—	—	—	0.7/18	—	([1])/2	—	—	—	—
Smilacina racemosa	0.8/12	([1])/2	—	—	0.7/8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Solidago spathulata	—	—	—	1/10	0.6/4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Stellaria jamesiana	—	([1])/2	—	—	—	4/30	3.5/40	—	—	6/38	0.7/18	0.7/6	([1])/4	—	2.7/28	1.6/26	—	—	—	—	1.8/22	—	—	4.8/64	—	([1])/6
Streptopus amplexifolius	—	—	([1])/4	—	—	—	—	([1])/4	—	—	—	—	—	—	—	—	—	—	([1])/4	—	—	—	—	—	—	—
Taraxacum sp.	0.6/4	—	0.5/10	0.7/6	([1])/2	—	([1])/2	2.2/26	([1])/2	([1])/2	—	2.3/22	2.6/24	—	4.8/40	8.8/50	2.3/22	—	—	—	1/10	—	—	—	—	([1])/2
Thalictrum fendleri	63/100	29/86	26/70	20/50	—	16/52	32/78	—	6/26	6.8/15	22/84	45/86	5.4/30	11/50	34/82	7.4/18	1.1/4	11/32	2.7/10	56/98	33/86	—	31/66	6.8/14	5/26	10/22
Thermopsis montana	—	—	—	—	—	—	—	—	—	—	10/48	([1])/2	15/54	—	—	1.1/6	—	—	—	—	—	—	—	—	—	—
Thlaspi montanum	—	—	—	—	—	—	—	—	5.7/50	—	—	—	—	—	—	([1])/2	—	—	—	1.6/32	—	7.8/56	1.3/22	—	—	—
Trillium ovatum	—	—	—	—	—	—	—	—	—	—	([1])/6	—	—	—	([1])/2	0.6/26	([1])/6	—	—	—	—	0.8/14	0.6/4	—	3.3/36	—
Valeriana occidentalis	—	—	—	—	1/10	([1])/4	—	—	2.9/12	4.7/24	2.7/18	8.5/42	—	0.6/4	25/66	13/50	2.7/18	—	—	—	6.1/40	15/42	24/66	—	—	—
Veratrum tenuipetalum	—	—	—	—	8.6/22	—	—	—	([1])/2	([1])/4	—	—	—	—	1.1/6	6.3/22	—	—	—	—	—	—	—	—	—	—
Vicia americana	2.2/12	1.2/18	—	24/62	—	([1])/6	1/8	4.7/40	—	([1])/2	4.8/28	1.4/6	16/68	0.7/6	6/30	4.2/22	12/48	31/88	13/52	1.5/20	9.3/50	0.7/6	10/46	6.5/38	8.3/42	36/92
Viola canadensis	—	—	—	—	—	—	([1])/2	—	—	—	—	([1])/4	—	—	—	—	—	—	—	—	—	—	—	—	0.6/12	—
Viola nuttallii	([1])/2	—	—	—	([1])/2	—	0.6/14	—	2.3/22	1.3/20	([1])/4	0.5/10	0.9/14	5.6/56	2.8/28	3.8/30	1/10	—	—	0.8/24	—	1.2/20	—	3.2/30	3.7/48	2.3/24
Zigadenus elegans	—	—	—	—	([1])/2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[1]Coverage of less than 0.5%.

Table A-6.—Location, topographic position, coverage (percent), and frequency (percent) of undergrowth species in stands of *Populus tremuloides/Heracleum sphondyllium*, *P. tremuloides/Veratrum tenuipetalum*, and *P. tremuloides/Pteridium aquilinum* habitat types

	Stand number													
	Populus/ Heracleum				*Populus/ Veratrum*			*Populus/Pteridium*						
	20	37	8	49	5	62	71	24	59	18	89	36	52	53
Location:														
Section	12	22	12	2	30	20	25	36	26	27	26	15	15	15
Township	1N	9N	10N	10N	3N	9N	10N	5N	5N	7N	7N	9N	9N	9N
Range	86W	87W	86W	86W	86W	84W	84W	84W	84W	84W	84W	89W	89W	89W
Topographic position:														
Slope	27%	5%	21%	29%	—	—	18%	29%	33%	4%	25%	20%	30%	28%
Aspect	216°	356°	201°	181°	—	—	186°	181°	196°	336°	322°	86°	106°	106°
Elevation (m)	2,444	2,475	2,606	2,688	2,682	2,682	2,682	2,682	2,475	2,512	2,548	2,755	2,743	2,731
	Coverage/Frequency													
Shrubs														
Abies lasiocarpa	—	—	—	—	—	—	0.8/2	—	—	—	—	—	(1)/2	—
Amelanchier alnifolia	—	—	—	—	—	—	—	—	6.8/30	—	—	—	7/30	1.3/2
Lonicera involucrata	—	—	—	—	—	—	—	—	—	2/4	—	—	—	—
Mahonia repens	—	—	—	—	—	—	—	—	2.4/16	—	—	—	(1)/4	—
Pachistima myrsinites	—	—	—	—	—	—	—	6.7/22	(1)/2	—	—	—	—	—
Populus tremuloides	—	1/8	—	6.6/26	—	1.5/4	(1)/4	—	—	—	—	—	3.4/12	1.2/2
Prunus virginiana	—	—	—	—	—	—	—	—	3.6/18	—	—	—	—	—
Quercus gambelii	—	—	—	—	—	—	—	—	2/4	—	—	—	—	—
Rosa woodsii	—	—	—	—	—	2.2/10	—	1.1/12	1.3/12	—	—	—	(1)/2	—
Rubus parviflorus	—	—	—	—	—	—	—	—	—	—	6.4/16	—	—	—
Sorbus scopulina	—	—	—	—	—	—	—	(1)/2	30/52	—	—	—	—	—
Symphoricarpos oreophilus	—	—	2.3/6	—	—	—	—	—	3.8/8	—	2.2/20	—	—	—
Graminoids														
Bromus anomalous	—	2.4/10	—	—	—	4/18	2.8/14	—	—	3.3/32	2.9/34	3/18	—	(1)/8
Bromus ciliatus	7.2/48	7.1/40	—	1.3/10	15/64	8/58	11/56	1.4/6	2.7/12	—	15/72	13/56	—	1.2/12
Calamagrostis canadensis	—	—	—	—	—	—	—	1.4/8	—	—	—	—	—	—
Calamagrostis rubescens	2.1/14	—	—	8.1/28	—	—	—	—	—	—	—	—	—	—
Carex geyeri	—	(1)/2	—	7.8/20	—	(1)/2	—	49/84	41/84	(1)/2	2.6/14	—	21/88	12/34
Carex laeviculmis	—	—	—	—	—	0.6/8	(1)/4	—	—	2.2/14	—	—	—	—
Carex raynoldsii	0.6/4	—	—	—	—	—	2.4/17	—	—	—	—	(1)/4	—	—
Elymus glaucus	17/88	11/56	27/92	36/96	—	—	2/10	25/66	11/46	10/58	17/84	21/78	20/60	25/80
Melica spectabilis	—	—	(1)/6	—	(1)/4	—	5.9/38	—	—	—	—	—	—	—
Phleum pratense	—	—	—	—	—	—	(1)/6	—	—	—	—	—	—	—
Poa canbyi	—	—	(1)/4	—	—	—	—	—	—	—	—	—	(1)/2	—
Poa interior	(1)/6	—	3.3/20	—	—	(1)/4	—	—	(1)/6	—	1.8/20	—	—	(1)/4
Poa leptocoma	—	—	1.2/10	(1)/4	—	(1)/6	—	3.4/40	—	1.4/16	(1)/6	0.6/10	—	—
Poa palustris	—	2.3/12	1.0/12	—	17/68	4/38	8.3/42	—	—	—	—	(1)/4	—	—
Poa pratensis	(1)/4	—	—	—	—	0.6/10	—	—	—	—	—	—	—	—

Forbs														
Achillea millefolium	—	—	—	—	—	6.6/68	9.2/32	—	([1])/4	([1])/2	—	([1])/2	—	([1])/4
Aconitum columbianum	—	2.4/10	—	—	0.8/4	—	—	2.2/6	([1])/2	1.6/10	—	—	—	([1])/2
Actaea rubra	—	—	—	—	—	—	—	—	—	—	—	—	([1])/2	—
Agastache urticifolia	—	—	([1])/4	—	—	—	3.4/18	—	—	0.6/4	3.8/32	1.4/14	([1])/2	([1])/2
Androsace septentrionalis puberulenta	—	—	—	—	—	—	([1])/4	—	—	—	—	([1])/2	—	—
Aquilegia caerulea	—	—	2.8/22	([1])/2	—	—	—	—	([1])/2	1.4/6	([1])/4	—	—	—
Arnica cordifolia	—	—	—	([1])/4	—	—	—	—	—	([1])/2	—	—	—	([1])/2
Aster engelmannii	([1])/4	([1])/4	—	6.1/34	—	6/36	—	8.2/36	20/62	5.7/24	2.5/12	4.8/18	12/52	6.7/36
Castilleja miniata	—	—	—	—	—	—	—	([1])/2	—	—	—	—	—	—
Chenopodium atrovirens	—	—	—	—	—	—	—	—	—	—	—	—	—	([1])/2
Cirsium sp.	—	—	—	—	—	—	([1])/2	1.3/12	3.9/20	—	—	—	0.7/6	—
Collomia linearis	—	—	—	—	—	1.4/16	—	—	—	—	—	—	—	—
Delphinium barbeyi	16/78	19/70	([1])/2	([1])/2	31/72	([1])/4	1.1/6	([1])/2	([1])/2	3.9/26	4.4/24	4.3/16	—	([1])/2
Delphinium nelsonii	—	—	—	—	—	—	([1])/4	—	—	—	—	—	—	—
Descurainia californica	—	2.2/18	—	—	—	—	—	—	—	—	—	([1])/6	—	([1])/2
Epilobium angustifolium	—	—	—	([1])/6	—	—	—	2.3/14	0.7/6	—	—	2.3/20	3.6/20	([1])/20
Equisetum arvense	—	—	—	—	—	—	1.9/10	—	—	—	—	—	—	—
Erigeron coulteri	([1])/2	—	([1])/2	—	—	—	—	—	—	—	1.8/12	—	([1])/2	—
Erigeron elatior	—	—	([1])/2	—	1.2/8	3.2/12	9.4/30	—	—	0.6/10	—	—	—	—
Erigeron speciosus	—	—	—	—	—	—	1.3/10	([1])/2	—	0.6/6	—	([1])/2	—	([1])/2
Fragaria sp.	—	—	3/20	1.2/8	([1])/6	8.3/64	—	0.8/12	([1])/2	0.4/6	—	([1])/2	1.5/12	0.9/26
Galium aparine	—	—	—	—	—	—	0.8/2	—	—	5.3/20	([1])/2	—	—	—
Galium boreale	—	—	([1])/2	([1])/4	4.3/26	3.7/30	5.9/36	3.6/34	([1])/8	2.1/24	([1])/2	1.2/10	([1])/10	1.6/14
Geranium richardsonii	7.8/68	0.7/6	27/88	16/78	5.9/40	14/66	4.1/24	9.7/38	15/52	12/64	([1])/2	8.8/36	3.9/14	18/70
Heliomeris multiflora	—	—	—	—	—	—	—	—	—	([1])/2	—	—	—	—
Heracleum sphondyllium	36/98	80/100	19/42	41/86	—	—	4.8/20	19/48	([1])/2	11/24	5.1/12	—	—	—
Hydrophyllum capitatum	8.3/58	—	—	—	23/66	([1])/2	3.3/32	—	—	—	([1])/4	—	—	—
Lathyrus leucanthus	—	—	([1])/2	4.1/20	—	—	4/30	1.1/6	8.6/38	1.4/6	—	3.2/26	0.7/6	—
Ligusticum porteri	([1])/4	—	16/46	19/62	7.7/14	29/68	2.1/14	7.6/16	21/48	2.3/6	2.4/8	2.3/6	0.7/2	14/32
Lupinus argenteus rubricaulis	—	—	([1])/2	—	—	1.8/14	—	([1])/2	1.5/12	—	—	—	7/42	2/10
Mertensia ciliata	3.5/30	5/26	—	—	2.2/12	1.3/2	4.4/24	—	—	0.7/8	—	1.1/4	—	1.4/6
Nemophila brevifolia	—	—	([1])/4	—	—	2.5/40	10/22	—	—	—	—	—	—	—
Osmorhiza sp.	—	([1])/6	—	6.8/30	—	5.2/30	7/40	—	11/54	7.7/38	3.6/20	7.5/48	16/56	0.6/4
Potentilla gracilis	—	—	—	—	—	([1])/6	([1])/2	—	—	—	—	—	—	([1])/2
Potentilla quinquefolia	—	—	([1])/2	—	—	—	—	—	—	—	([1])/4	—	—	—
Prunella vulgaris	—	—	—	—	—	—	([1])/6	—	—	—	([1])/2	—	—	—
Pseudocymopteris montanus	—	—	—	—	—	—	—	([1])/2	—	—	—	—	—	—
Pteridium aquilinum	—	—	—	1.1/4	0.8/2	—	—	64/90	48/80	48/90	58/90	71/98	62/88	74/100
Ranunculus alismaefolius	—	—	—	—	—	([1])/2	—	—	—	—	—	—	—	—
Ranunculus inamoenus	—	—	([1])/4	—	—	—	0.6/6	—	—	([1])/4	—	—	—	—
Ranunculus uncinatus parviflorus	([1])/2	—	([1])/2	—	—	2.2/20	1.4/8	—	—	—	—	—	—	—
Senecio serra	0.7/6	1.7/16	—	([1])/4	0.6/4	—	([1])/4	—	—	4.4/38	([1])/4	2/18	([1])/2	5.5/28
Silene menziesii	—	—	2.9/10	([1])/2	—	—	([1])/6	—	([1])/10	—	—	([1])/16	([1])/2	—
Smilacina racemosa	—	—	—	—	—	—	—	—	3.4/10	—	—	—	—	—
Stellaria jamesiana	—	([1])/2	—	—	0.7/8	([1])/2	—	([1])/2	([1])/2	0.9/16	6.2/50	([1])/12	([1])/18	([1])/2
Streptopus amplexifolius	—	—	—	—	—	—	—	—	([1])/2	—	—	—	—	—
Taraxacum sp.	0.7/6	—	([1])/2	([1])/2	—	11/44	0.6/6	0.5/8	—	([1])/2	—	—	—	—
Thalictrum fendleri	28/70	0.9/6	25/90	13/56	9.5/38	—	3.9/12	17/30	17/52	15/40	44/86	14/32	33/88	18/56
Thermopsis montana	—	—	([1])/6	—	—	1.1/22	—	—	—	—	([1])/2	—	—	1.4/6
Thlaspi montanum	—	—	—	—	—	—	1.1/22	—	—	—	—	([1])/2	—	—
Trillium ovatum	—	—	—	—	—	2.2/38	—	—	—	—	—	—	—	—
Valeriana occidentalis	2/20	0.8/10	0.9/6	—	1.9/16	1.7/8	0.8/2	—	—	—	—	3.2/20	—	2.7/20
Veratrum tenuipetalum	([1])/2	—	—	1.1/4	3/14	9.7/30	27/56	—	—	—	5.4/18	—	—	3.3/10
Vicia americana	—	—	([1])/2	3.8/24	—	2.3/20	—	27/88	2.5/22	3.2/20	([1])/2	1.4/8	9/30	1.6/14
Viola canadensis rugulosa	—	0.6/34	—	—	—	([1])/6	—	—	—	—	—	—	—	—
Viola nuttallii	7.1/44	—	1.4/14	—	—	—	1.7/28	—	([1])/12	1.1/12	1/28	([1])/2	—	—

[1]*Coverage of less than 0.5%.*

Table A-7.—Location, topographic position, coverage (percent), and frequency (percent) of undergrowth species in stands of the *Abies lasiocarpa/Vaccinium scoparium* habitat type

	Stand number																								
	41	43	56	85	86	87	93	1	2	28	3	47	48	50	51	57	58	63	64	60	96	97	30	45	73
Location:																									
Section	29	36	32	21	29	4	20	34	35	32	10	15	9	19	19	15	13	13	8	22	8	24	32	28	9
Township	5N	5N	5N	2S	3S	1S	3N	10N	10N	10N	10N	11N	11N	11N	11N	12N	12N	10N	9N	5N	5N	5N	5N	6N	7N
Range	80W	78W	80W	77W	77W	77W	78W	88W	88W	88W	86W	85W	85W	84W	84W	85W	85W	84W	84W	83W	83W	83W	82W	82W	82W
Topographic position:																									
Slope	25%	21%	10%	33%	24%	8%	25%	17%	21%	25%	30%	—	—	—	—	32%	—	10%	30%	—	5%	39%	—	15%	—
Aspect	241°	1°	51°	233°	56°	296°	6°	327°	23°	296°	121°	—	—	—	—	216°	—	276°	306°	—	226°	76°	—	5°	—
Elevation (m)	3,048	2,865	3,048	3,078	2,972	2,926	2,850	2,950	2,914	2,914	2,560	2,658	2,609	2,743	2,755	2,743	2,743	2,829	2,365	2,871	2,981	2,957	2,897	2,792	2,591
	Coverage/Frequency																								
Shrubs																									
Abies lasiocarpa	5.1/22	2.3/14	5.6/14	—	1.4/20	6.1/20	—	1/8	0.5/2	5.5/18	4.8/10	—	(')/4	2/18	4.1/56	2/12	1.8/12	—	1.2/14	18/40	(')/4	3.1/8	2.8/6	(')/4	(')/2
Amalanchier alnifolia	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(')/2	—	—	—	—	—	—	—	—	(')/2
Ceanothus velutinus	—	—	—	—	—	—	—	—	—	(')/2	—	1.2/8	—	—	—	—	—	(')/2	—	—	—	—	—	—	—
Chimaphila umbellata	6.4/24	—	—	—	—	—	—	—	—	—	(')/10	—	—	—	—	—	—	—	—	—	—	—	—	—	(')/2
Juniperus communis	1/4	—	—	3.3/8	3.9/10	—	1.6/14	—	—	—	—	—	—	—	—	—	—	—	(')/4	—	—	—	—	—	1.7/20
Linnaea borealis	—	—	—	—	4.8/30	—	—	—	—	—	—	—	—	—	—	—	—	—	0.6/4	—	—	—	—	—	—
Lonicera involucrata	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(')/2	3/14
Mahonia repens	—	—	—	(')/2	(')/4	—	—	—	—	—	—	—	—	—	—	0.8/10	—	—	—	—	—	—	—	—	—
Moneses uniflora	—	—	—	—	—	—	(')/2	—	—	(')/2	0.5/10	(')/4	—	—	—	—	—	—	(')/4	—	—	—	—	—	—
Pachistima myrsinites	2/20	2.9/36	1.6/22	0.5/8	1.6/22	—	—	0.8/18	3.8/26	1.1/22	5.6/58	—	1.1/6	—	(')/4	(')/8	(')/2	1.9/34	2.6/16	—	—	—	—	4.6/44	(')/2
Picea engalmannii	—	(')/2	—	(')/4	—	—	1/4	—	—	(')/2	0.6/4	—	—	—	—	—	—	—	—	—	(')/2	—	0.8/4	(')/2	—
Pinus contorta	—	(')/2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(')/2	—	(')/2	—	—
Pyrola virens	—	—	0.5/14	—	—	—	1.4/22	—	(')/6	(')/4	0.6/20	—	—	—	(')/4	—	—	—	—	(')/2	—	—	—	—	—
Ramischia secunda	0.6/12	(')/2	5.1/58	—	—	(')/2	(')/2	2/20	4.2/36	1.5/38	(')/2	2/28	—	0.6/4	(')/2	—	(')/2	—	—	(')/4	—	—	(')/6	3.2/50	(')/4
Ribes montigenum	—	—	—	—	—	—	—	(')/2	—	—	—	—	—	—	—	—	—	(')/2	—	—	—	—	—	2.3/14	—
Rosa sp.	—	—	(')/4	—	1.4/16	—	—	—	—	—	—	0.8/12	(')/2	—	—	—	—	—	3.5/22	—	—	—	—	—	6.8/38
Rubus parviflorus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.1/18	—	—	—	—	—	—
Shepherdia canadensis	—	—	—	—	—	—	2.8/6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sorbus scopulina	—	—	—	—	—	—	—	—	0.6/4	(')/4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Vaccinium caspitosum	—	—	—	—	—	—	—	—	—	4.2/40	—	8.5/42	—	—	—	(')/2	—	—	—	—	—	—	—	—	—
Vaccinium myrtillus	1.1/14	1.1/12	3.1/24	6.8/32	16/52	23/78	21/78	—	—	—	—	(')/2	—	—	—	2.2/28	(')/6	3.1/16	40/94	—	5.6/34	2/22	8.6/42	6.7/20	18/58
Vaccinium scoparium	31/80	33/74	17/40	41/100	24/62	69/100	56/100	80/100	17/66	17/64	46/84	17/52	13/46	22/46	55/92	63/100	43/88	47/94	20/52	68/94	50/86	72/100	30/66	24/54	12/32
Graminoids																									
Bromus ciliatus	—	—	—	—	—	—	—	—	—	(')/2	—	(')/6	—	—	—	—	3/20	—	(')/4	—	(')/6	(')/2	—	(')/4	—
Calamagrostis rubescens	—	—	—	—	—	—	—	—	—	—	—	12/50	62/98	—	(')/4	—	—	—	23/88	—	—	—	—	—	—
Carex geyeri	16/32	(')/6	1.4/6	(')/2	3.2/14	—	—	—	9/22	(')/2	—	—	—	17/66	2.6/16	19/80	7.7/22	(')/2	(')/2	(')/4	0.8/12	4.5/16	—	4/14	—
Elymus glaucus	—	—	—	—	—	—	—	—	—	—	—	0.8/10	—	—	—	—	(')/2	—	—	(')/2	—	—	—	(')/2	1.3/10
Poa leptocoma	—	—	(')/6	—	—	—	—	—	0.7/18	—	—	—	—	—	—	—	—	(')/4	—	—	—	(')/2	—	(')/4	—
Poa nervosa	(')/4	—	—	0.6/14	—	—	(')/6	—	—	(')/4	—	—	—	(')/2	—	(')/2	—	—	—	—	(')/4	—	—	—	—
Trisetum spicatum	—	(')/2	—	—	0.7/14	—	—	—	—	—	(')/6	—	—	—	—	—	(')/2	—	—	(')/6	—	—	(')/2	—	—
Forbs																									
Achillea millefolium	—	—	—	—	—	—	—	—	—	—	—	—	(')/2	—	—	—	—	—	—	(')/2	(')/2	—	—	—	—
Anaphalis margaritacea	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2/10	—	0.5/10	—	—
Antennaria microphylla	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(')/2	—	(')/4
Arnica cordifolia	0.8/12	(')/4	4.4/22	2.8/26	(')/4	(')/2	0.6/14	1.3/30	8.5/64	18/90	11/64	2.6/26	2/40	17/92	3.2/46	3.4/36	3.1/44	0.5/20	5.3/44	1.2/10	2.3/14	—	1.8/20	11/70	9/68
Arnica latifolia	(')/4	—	(')/6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.1/28	—	—	—	—
Arnica parryi	—	—	—	—	—	—	—	—	—	(')/4	—	—	—	—	—	—	—	—	—	—	—	—	(')/2	—	—
Aster angelmannil	—	—	—	—	—	—	—	—	—	—	—	(')/2	—	—	(')/4	(')/4	(')/2	—	—	—	0.8/4	—	—	5.3/28	—
Astar foliaceous	—	—	—	—	—	—	—	—	—	(')/4	—	—	—	—	—	—	—	—	—	—	—	(')/2	—	—	—
Campanula rotundifolia	—	(')/2	—	—	—	—	—	—	—	—	—	—	(')/2	—	—	—	—	—	—	—	—	—	—	—	—
Castilleja sulphurea	—	—	—	(')/4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Delphinium barbeyi	—	—	—	—	—	—	—	—	—	—	—	1.3/12	—	—	—	—	—	—	—	—	—	—	—	0.9/6	—
Epilobium angustifolium	—	—	—	—	—	0.8/12	(')/2	—	(')/10	—	(')/2	(')/8	(')/2	—	—	—	—	—	2.5/28	1.5/20	—	—	(')/4	(')/2	0.5/8
Erigeron peregrinus callianthamus	—	—	—	—	—	—	—	—	—	—	—	2/14	—	—	—	—	0.5/8	—	(')/6	2/20	—	—	—	—	—
Fragaria sp.	—	(')/2	—	—	—	—	—	—	—	—	—	1.3/30	(')/6	—	—	—	(')/12	—	(')/4	1.5/10	—	—	—	—	1.9/24

	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(¹)/2	—
Galium boreale	—	—	—	—	—	—	—	—	—	—	—	2/32	—	—	—	—	—	—	(¹)/2	—	—	—	—	—	(¹)/4
Geranium richardsonii	—	—	—	—	—	—	—	—	—	(¹)/2	—	3.9/36	—	—	—	—	0.5/10	—	—	—	—	—	—	6/30	—
Goodyera oblongifolia	—	—	—	—	—	—	—	—	—	—	(¹)/2	(¹)/2	—	—	—	—	—	—	—	—	—	—	—	—	(¹)/2
Haplopappus parryi	—	0.8/10	—	—	—	—	—	—	(¹)/4	—	—	(¹)/2	—	—	—	—	—	—	—	—	—	—	—	—	—
Heracleum sphondyllium	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(¹)/6	—
Heuchera parviflora	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—	—	—	—	(¹)/2	—
Hieracium albiflorum	—	—	—	—	—	—	—	—	—	—	—	—	—	(¹)/4	1/20	0.6/4	—	—	—	(¹)/4	1.2/18	(¹)/2	(¹)/2	—	—
Lathyrus leucanthus	—	—	—	—	—	—	—	—	(¹)/4	(¹)/2	—	—	4.2/32	(¹)/4	—	—	—	—	7.7/28	—	—	—	—	1.4/8	4.5/24
Ligusticum porteri	—	—	—	—	—	—	—	—	—	—	—	0.8/10	—	—	—	—	—	—	—	2.2/12	0.6/4	—	—	2.7/10	—
Lupinus argenteus rubricaulis	1.4/6	3/14	—	—	—	1.3/4	—	—	—	(¹)/8	—	(¹)/4	5.8/48	—	(¹)/2	3.3/14	—	—	1.6/6	1.2/10	1.4/6	0.5/8	—	—	—
Mosses and lichens	3.2/14	8/50	6.2/28	5.7/38	20/80	2.1/8	7.6/36	5.8/54	1/10	5.5/36	7/32	8.8/34	0.8/14	(¹)/2	2.8/16	1.5/12	3.8/18	7/32	5/18	8.5/24	20/38	5.1/22	9.9/34	9.6/24	(¹)/6
Osmorhiza sp.	—	—	(¹)/2	—	—	—	—	(¹)/2	(¹)/4	0.5/10	2.1/18	(¹)/10	(¹)/2	(¹)/8	—	—	2.4/16	—	(¹)/4	(¹)/6	—	—	—	0.7/6	—
Pedicularis bracteosa paysoniana	—	—	—	—	—	—	—	(¹)/2	(¹)/2	—	—	—	—	—	—	—	—	—	—	—	—	—	(¹)/4	—	—
Pedicularis racemosa	—	—	—	—	(¹)/2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.8/2	—	—
Potentilla gracilis	—	—	—	—	—	—	—	—	—	—	—	—	—	(¹)/2	—	—	—	—	—	—	—	—	—	—	—
Pseudocymopteris montanus	—	—	—	—	—	—	—	—	—	—	—	—	—	(¹)/2	(¹)/2	—	1.9/26	—	—	—	—	—	—	—	0.7/6
Ranunculus uncinatus parviflorus	—	—	—	—	—	—	—	—	—	—	(¹)/2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Senecio wootonii	—	—	—	—	—	(¹)/2	—	—	—	1.2/20	—	—	—	—	—	—	—	—	—	—	—	—	(¹)/2	—	—
Silene menziesii	—	—	—	—	—	—	—	—	—	—	—	—	—	(¹)/2	—	—	—	—	—	—	—	—	—	—	—
Smilacina racemosa	—	—	—	—	—	—	—	(¹)/2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(¹)/4	—
Solidago multiradiata scopulorum	—	—	—	—	—	—	(¹)/2	—	(¹)/2	—	—	(¹)/6	—	—	0.9/6	—	—	—	—	—	—	—	—	0.6/4	6.2/60
Solidago spathulata neomexicana	—	(¹)/2	—	2.5/14	—	—	—	—	—	—	—	—	—	(¹)/8	—	—	—	—	(¹)/4	1.6/14	1.3/12	—	—	—	—
Streptopus amplexifolius	—	—	—	—	—	—	—	—	—	—	—	1.5/18	—	—	—	—	—	—	—	—	—	—	—	1.3/10	—
Thalictrum fendleri	—	—	—	—	—	—	—	—	1.1/6	—	—	0.8/10	—	—	—	—	—	—	—	—	—	—	—	(¹)/4	—
Thermopsis montana	—	—	—	—	—	—	—	—	1/8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Trillium ovatum	—	—	—	—	—	—	—	—	—	(¹)/2	—	(¹)/8	—	—	—	—	—	—	—	—	—	—	—	(¹)/2	0.5/12
Vicia americana	—	—	—	—	—	—	—	—	—	—	—	—	0.8/10	—	—	—	—	—	0.9/6	—	—	—	—	(¹)/2	—
Viola nuttallii	—	—	—	—	—	—	—	—	(¹)/2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.9/6	—
Zigadenus elegans	—	—	—	—	—	—	—	—	—	—	—	(¹)/2	—	—	—	—	—	—	—	—	—	—	—	—	(¹)/2

[1]Coverage of less than 0.5%.

Table A-8.—Location, topographic position, coverage (percent) and frequency (percent) of undergrowth species in stands of the *Pinus contorta/Shepherdia canadensis* habitat type

	Stand number					
	40	44	82	83	31	33
Location:						
Section	20	25	21	29	20	19
Township	5N	5N	5N	5N	2N	2N
Range	80W	78W	78W	78W	82W	82W
Topographic position:						
Slope	5%	—	11%	25%	17%	21%
Aspect	251°	—	286°	131°	201°	159°
Elevation (m)	2,834	2,829	2,755	2,911	2,938	2,950
	Coverage/Frequency					
Shrubs						
Abies lasiocarpa	0.8/2	—	—	—	—	—
Arctostaphylos uva-ursi	—	(1)/2	—	—	—	—
Juniperus communis	2.7/12	8.8/18	10/20	9/26	2.4/8	4.9/12
Mahonia repens	—	—	1.8/14	0.5/10	0.5/10	1.3/14
Moneses uniflora	(1)/2	—	—	(1)/6	—	—
Pachistima myrsinites	6/46	—	1.1/6	10/58	0.9/14	1.4/16
Pinus contorta	—	1.9/6	—	—	—	—
Ramischia secunda	—	(1)/6	(1)/4	—	(1)/2	(1)/4
Rosa sp.	—	7.6/58	9/68	1.7/20	2.6/34	6.1/50
Shepherdia canadensis	31/70	11/18	5.7/10	3.6/18	25/52	34/54
Vaccinium cespitosum	0.7/8	9.7/66	—	—	—	—
Vaccinium myrtillus	—	0.7/8	5.8/62	17/70	25/86	15/62
Vaccinium scoparium	47/98	10/56	4.6/14	22/72	—	1.1/12
Graminoids						
Bromus ciliatus	—	—	—	—	—	(1)/2
Carex geyeri	—	4.8/18	1.2/2	—	9.8/25	1.6/6
Poa nervosa	(1)/4	—	—	—	0.6/8	—
Stipa lettermani	—	—	(1)/2	—	—	—
Trisetum spicatum	—	(1)/6	(1)/2	—	—	—
Forbs						
Anaphalis margaritacea	(1)/4	—	—	—	—	—
Arnica cordifolia	0.9/16	4.3/44	5.1/50	1.1/22	1.6/34	3.2/22
Campanula rotundifolia	—	—	(1)/2	—	—	—
Epilobium angustifolium	—	0.5/10	(1)/6	—	—	0.9/14
Erigeron speciosus	—	—	—	—	—	(1)/2
Fragaria sp.	—	0.5/8	0.5/20	—	—	(1)/2
Hieracium albiflorum	—	—	—	—	0.9/14	—
Lathyrus leucanthus	—	—	6/26	—	—	—
Lupinus argenteus rubricaulis	—	8.1/52	0.5/8	—	—	—
Mosses and lichens	3.8/16	0.7/8	1.6/8	3.1/18	1.8/22	3.4/18
Phlox sp.	—	—	—	—	—	(1)/2
Senecio wootonii	—	—	—	—	(1)/6	—
Solidago multiradiata	—	2.8/32	1.9/26	—	—	(1)/2
Solidago spathulata	—	—	—	—	—	(1)/4

Table A-9.—Location, topographic position, coverage (percent) and frequency (percent) of undergrowth species in stands of the *Abies lasiocarpa/Carex geyeri* habitat type

	Stand number										
	54	55	4	16	29	7	15	34	68	61	46
Location:											
Section	25	29	30	30	2	12	19	26	16	17	21
Township	5N	5N	3N	3N	9N	10N	11N	11N	11N	9N	7N
Range	81W	81W	86W	86W	88W	86W	84W	85W	85W	84W	82W
Topographic position:											
Slope	15%	11%	25%	15%	26%	20%	4%	5%	—	21%	—
Aspect	166°	178°	51°	331°	176°	116°	80°	339°	—	266°	—
Elevation (m)	2,926	2,952	2,667	2,682	2,804	2,652	2,792	2,621	2,557	2,411	2,633
	Coverage/Frequency										
Shrubs											
Abies lasiocarpa	16/30	12/22	—	2.2/12	13/22	—	—	10/34	—	—	—
Chimaphila umbellata	—	0.7/18	—	—	—	—	—	—	—	—	—
Juniperus communis	(1)/2	(1)/6	—	—	—	—	—	—	—	—	—
Mahonia repens	0.7/6	0.5/10	—	0.5/10	(1)/2	(1)/8	—	—	—	1.9/18	(1)/2
Pachistima myrsinites	0.8/10	2/40	—	0.7/8	1.5/28	—	(1)/2	—	(1)/4	2.5/12	(1)/4
Picea engelmannii	—	—	—	—	—	—	—	(1)/4	—	—	—
Populus tremuloides	—	—	—	—	—	—	(1)/6	—	—	—	—
Ramischia secunda	—	(1)/2	—	—	(1)/4	—	—	0.7/8	—	—	(1)/2
Rosa sp.	0.8/10	0.9/14	2.3/6	1.6/22	1/10	—	—	—	4.4/32	1.9/16	8.2/40
Sambucus racemosa	—	—	—	(1)/2	—	(1)/2	—	—	—	—	—
Symphoricarpos oreophilus	—	—	1.1/6	4/18	—	(1)/2	—	—	—	—	0.7/6
Vaccinium scoparium	11/32	4.4/6	—	—	8.8/24	—	—	(1)/2	—	—	(1)/2
Graminoids											
Agropyron elongatum	—	—	—	—	—	—	—	—	—	—	(1)/2
Bromus anomalous	—	—	—	(1)/4	—	—	—	—	—	—	—
Bromus ciliatus	—	—	12/60	—	—	(1)/2	—	—	—	1.1/10	—
Calamagrostis rubescens	—	—	—	—	—	12/32	—	(1)/2	26/88	50/100	—
Carex geyeri	45/86	32/76	5.4/16	10/36	24/82	32/62	20/84	10/38	36/86	12/70	15/64
Elymus glaucus	—	—	10/24	2.9/36	—	4.5/26	1.3/32	—	—	—	—
Melica spectabilis	—	—	—	—	—	—	—	—	—	(1)/10	—
Poa nervosa	—	—	—	—	(1)/2	—	(1)/4	—	—	—	—
Poa pratensis	—	—	1.1/6	—	—	—	—	—	—	—	—
Trisetum spicatum	—	(1)/4	—	—	—	—	—	—	—	—	—
Forbs											
Achillea millefolium	—	—	1.5/12	(1)/2	—	—	(1)/6	—	(1)/2	—	(1)/2
Agastache urticifolia	—	—	—	—	—	(1)/2	—	—	—	—	—
Aquilegia caerulea	—	—	—	(1)/6	—	—	—	—	—	—	—
Arabis drummondii	—	—	(1)/2	—	(1)/4	—	—	—	—	—	—
Arnica cordifolia	8.3/52	17/76	23/54	11/48	1/18	15/46	24/86	—	21/84	6.1/24	0.7/28
Aster engelmannii	—	—	—	—	0.5/10	—	—	—	—	—	(1)/2
Campanula rotundifolia	—	—	—	—	—	—	—	(1)/2	—	—	(1)/2
Castilleja sulphurea	—	—	3.3/18	3.7/32	—	—	—	—	(1)/2	3.4/28	—
Cirsium sp.	—	—	—	—	—	—	—	—	(1)/2	—	—
Collomia linearis	—	—	—	—	—	—	—	—	(1)/2	—	—
Delphinium barbeyi	—	—	—	—	—	—	—	—	—	(1)/2	—
Descurainia californica	—	—	—	—	—	(1)/2	—	—	—	—	—
Epilobium angustifolium	2.8/36	—	—	(1)/2	(1)/4	—	—	—	—	0.8/2	0.5/8
Erigeron elatior	—	—	3.9/10	—	(1)/4	—	—	—	—	—	—
Erigeron speciosus	—	—	—	(1)/2	—	—	(1)/2	—	—	—	—
Erythronium grandiflorum	—	—	—	—	—	—	2.2/26	—	—	—	—
Fragaria sp.	—	—	4.7/42	2.4/36	—	(1)/2	(1)/14	(1)/2	0.7/8	(1)/4	2.8/24
Galium boreale	—	—	2.4/26	—	—	(1)/2	—	—	(1)/6	—	(1)/4
Geranium richardsonii	—	—	—	0.6/12	—	—	(1)/4	—	—	(1)/6	1.2/16
Geranium viscosissimum	—	—	0.8/4	—	—	—	—	—	—	—	—
Helenium hoopesii	—	—	(1)/4	—	—	—	—	—	—	—	—
Lathyrus leucanthus	14/56	3.2/14	4.7/18	17/46	1/14	4.6/18	2.6/16	—	31/92	—	17/68
Ligusticum porteri	—	—	—	—	0.9/6	2.3/14	—	—	1.1/4	5.1/22	—
Lupinus argentus rubricaulis	—	—	31/92	4.3/40	0.5/10	—	6.4/42	—	1.7/20	1/10	1/10
Mosses and lichens	1.1/6	1.8/14	—	—	2.5/10	—	—	15/44	—	—	0.8/2
Nemophila breviflora	—	—	—	—	—	—	(1)/2	—	—	—	—
Osmorhiza sp.	(1)/6	—	7.7/48	1.3/30	(1)/6	2.7/20	1.1/24	0.5/10	0.5/10	(1)/2	1.5/28
Pedicularis racemosa	—	—	1.7/8	—	—	—	—	—	—	—	—
Penstemon whippleanus	—	—	(1)/2	—	—	—	—	—	—	—	—
Potentilla gracilis	—	—	—	(1)/2	—	—	—	—	(1)/2	—	(1)/2
Pseudocymopteris montanus	—	—	—	—	—	—	(1)/4	—	—	—	—
Senecio crassulus	—	—	—	2.8/24	—	—	—	—	—	(1)/2	—
Senecio wootonii	—	—	1.4/6	—	1/10	—	—	—	—	—	—
Silene menziesii	—	—	—	—	(1)/2	—	—	—	—	(1)/2	—
Solidago multiradiata	—	—	—	—	—	—	—	1/12	(1)/2	—	—
Solidago spathulata	1/10	0.5/8	—	—	—	—	—	—	—	—	(1)/4
Streptopus amplexifolius	—	—	—	—	—	—	—	—	—	—	0.8/6
Taraxacum sp.	—	—	—	(1)/6	—	—	—	—	(1)/2	(1)/4	(1)/8
Thalictrum fendleri	—	—	2/4	2.1/10	1.4/8	1.4/10	—	—	2.3/6	—	—
Thermopsis montana	—	—	—	—	5.1/30	—	—	—	—	—	—
Trillium ovatum	—	—	—	—	—	—	—	—	(1)/2	—	—
Veratrum tenuipetalum	—	—	—	—	1.1/4	—	—	—	—	(1)/2	1/8
Vicia americana	—	—	1.8/6	1.5/10	0.9/10	8.7/22	—	—	—	24/68	3.6/34
Viola nuttallii	—	—	(1)/2	—	—	(1)/2	1.4/26	—	—	—	—

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Hoffman, George R., and Robert R. Alexander. 1980. Forest vegetation of the Routt National Forest in northwestern Colorado: A habitat type classification. USDA Forest Service Research Paper RM-221, 41 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

A vegetation classification based on concepts and methods developed by Daubenmire were used to identify 11 forest habitat types in the Routt National Forest. Included were five habitat types in the *Populus tremuloides* series, two in the *Abies lasiocarpa* series, and one each in *Pinus contorta*, *Pseudotsuga menziesii*, *Pinus flexilis*, and *Quercus gambelii* series. A key to identify the habitat types and the management implications associated with each are provided.

Keywords: Vegetation classification, habitat type, *Abies lasiocarpa*, *Picea engelmannii*, *Pinus contorta*, *Pinus flexilis*, *Pseudotsuga menziesii*, *Populus tremuloides*, *Quercus gambelii*

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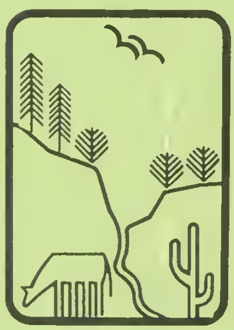
Rocky Mountains



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Rocky Mountain Forest and Range Experiment Station

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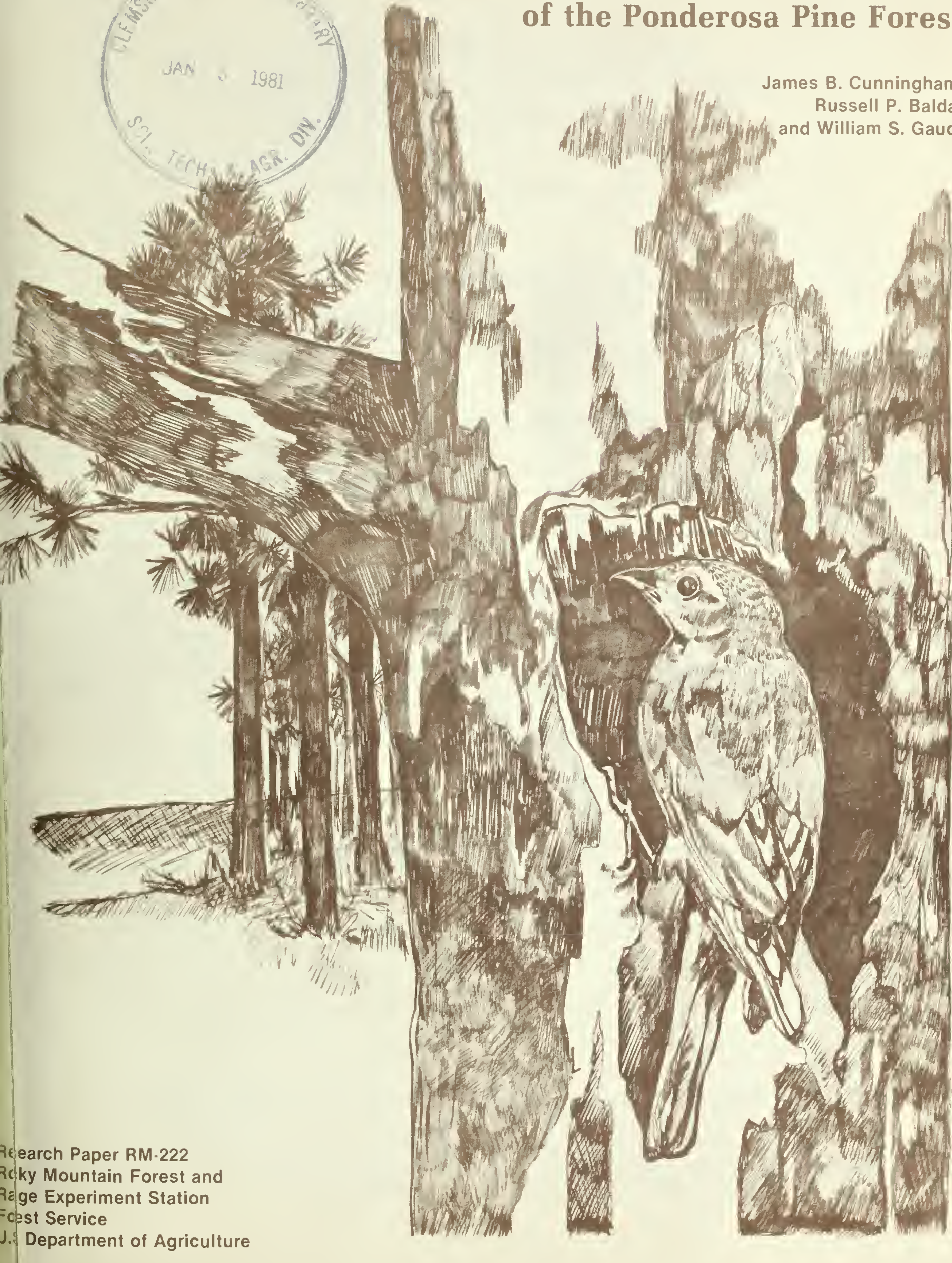
Selection and Use of Snags by Secondary Cavity-Nesting Birds of the Ponderosa Pine Forest

James B. Cunningham
Russell P. Balda
and William S. Gaud



Research Paper RM-222
Rocky Mountain Forest and
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September 198

Selection and Use of Snags by Secondary Cavity-Nesting Birds of the Ponderosa Pine Forest[1]

James B. Cunningham, Russell P. Balda, and William S. Gaud[2]

Abstract

One factor limiting the population size of secondary cavity-nesting birds in ponderosa pine is the number of suitable nesting cavities. Snags in the pine forest provide a large number of species with nesting and roosting sites. To maintain secondary cavity nesters at their natural population level, a density of 5.2 snags per ha is recommended for mature ponderosa pine.

[1]Research was conducted under cooperative agreement 16-539-CA with the Rocky Mountain Forest and Range Experiment Station with headquarters at Fort Collins in cooperation with Colorado State University. Supervision was provided by David R. Patton, project leader for wildlife habitat research, at the Station's Research Work Unit at Tempe, in cooperation with Arizona State University.

[2]The authors are Research Associate, Professor of Biology, and Assistant Professor of Biology, respectively, at Northern Arizona University, Flagstaff.

Selection and Use of Snags by Secondary Cavity-Nesting Birds of the Ponderosa Pine Forest

James B. Cunningham, Russell P. Balda, and William S. Gaud

Management Highlights

The results of this investigation indicate that snags ıre important as nest and roost sites; provide a large ıumber of bird species with hawking, singing and lrumming, or perching posts; and provide a feeding substrate for many species. The following guide to the :haracteristics of desirable snags is proposed:

1. Diameter of snags should be greater than 33 cm.
2. Total height of snags should be greater than 6 m.
3. Percent bark cover should be greater than 40%.
4. Snags which have broken tops should be saved if they also fit the above criteria.
5. Ponderosa pine snags in the most frequently used age range of 5-29 years should be saved.
6. In areas where the available snags are below the size range stated above, the largest snags should be saved.
7. Snags with existing cavities should be given preference.
8. In areas where oaks are found and oak removal is to occur, those oaks with a diameter of 27 cm and greater should be saved as suitable nest sites.
9. Secondary cavity nesters such as the white-breasted nuthatch utilize the dead strips from lightning strikes. Since such trees are usually poor quality timber trees, they should be saved for immediate use by the birds and as a means of producing future snags.
10. Hard snags could be removed in preference to soft snags, if necessary, but, if possible, hard snags should be saved as territory and perching posts.
11. Those live ponderosa pines with dead tops should be left for nest and roost sites and for future snag replacement.
12. Balda (1975) suggested that the density of snags should be 6.5 snags per ha to maintain secondary cavity nesters at natural levels. Evidence from this study indicates that 5.2 snags per ha is a more realistic density in a mature ponderosa pine forest.

Introduction

Cavity-nesting birds are a widespread and common group of species from many families and orders. (Scientific names of flora and fauna referred to in this paper ıre listed in the appendix.) Cavity-nesting birds sometimes roost in natural or excavated holes, crevices, or :avities in trees. Secondary cavity nesters (SCN's)—principally ascines (chickadees, tits, nuthatches, and ome creepers), wrens, flycatchers, bluebirds, wallows, starlings, and warblers—lack the morphoogical adaptations necessary for excavating their own avities. Most of them use natural cavities or cavities xcavated by woodpeckers. Thus, the number of suitble nesting cavities is the primary limiting factor on CN population size (Allen and Nice 1952; Balda 1970, 975; Burns 1960; Elliot 1945; von Haartman 1957; ower 1966; Zeleny 1972).

MacKenzie (1952) observed that SCN populations ıcreased when unlimited nesting and roosting sites ıesting boxes) were supplied. As long as there were sufficient nesting and roosting sites, other density-limiting factors, such as food, did not affect the population.

In the forests of Finland where silvicultural practices have been implemented, bird species diversity was always lower on treated compared to nontreated forests (Haapanen 1965). This difference was due primarily to the drastic reduction in the cavity-nesting species in the treated areas. The climax stage of the forest was the most favorable for cavity nesters because of the abundance of old and dying trees (Haapanen 1965). In 1971, von Haartman found that a reduction in nest box density had a drastic effect upon the density of the pied flycatcher, indicating that nesting sites were an important limiting factor for this cavity nester. If, on treated forests, no trees are allowed to grow beyond some predetermined maximum age, then no trees will reach a stage of rot or decay suitable to the formation of snags used by cavity-nesting birds.

Balda (1975) found violet-green swallows and mountain chickadees to be absent from areas where snags were also absent, indicating that the densities of these two species were directly related to snag density. An important source of nesting and roosting sites, hawking and foraging sites, and drumming posts for SCN's is snags, standing dead trees, or live trees with dead tops. Snags are produced by forest fires, insects, disease, lightning, and other factors. The number of snags available is, however, limited both by management practices and by natural factors.

Szaro and Balda (1979) found that insectivorous birds in the southwestern ponderosa pine forest spend about 10% of their time foraging on snags. Since snags comprise far less than 10% of the biomass of the forest, this indicates snags are a preferred foraging substrate. Swallows and bluebirds use snags extensively for hawking sites. Woodpeckers use snags as sites for drumming; whereas, other species use snags as singing perches when attracting mates and defending territories.

Snags are a fire hazard because of the tendency of burning snags to scatter hot material and thus spread fires (Keen 1929, 1955). They also pose a safety hazard to equipment operators in logging operations. For these reasons, snags commonly have been removed from a forest during timber harvest or fire-control operations. These snag removal practices, plus the heavy increase in the use of snags as fuelwood, have led to a drastic reduction in the number of snags on both public and private forest lands.

The short time snags naturally remain standing further limits the number of snags available to SCN's. In addition, snags are not utilized efficiently by SCN populations, making an abundant supply desirable. Not every snag or every cavity is suitable as a nesting site, nor will every type of SCN utilize every type of snag or cavity. Even during the breeding season, a high percentage of holes may be unoccupied (Dennis 1971), possibly because of strong cavity specificity of the different species.

Snags should be widely distributed because their location limits the habitat of individual birds to the immediate vicinity of the snag. Concentration of snags in limited areas and elimination of many snags has led to what appears to be severe intraspecific and interspecific competition for nesting sites. Such competition is normally rare among SCN's because encounters occur only in the immediate vicinity of the cavity entrance.

Pied flycatchers were found to defend the area around the cavity entrance from conspecifics and from other species such as the great tit (von Haartman 1957). In most cavity-nesting species, the male selects a suitable cavity and then attracts a female. Since the male must be near enough to the cavity to drive off potential competitors for the cavity and also to demonstrate the suitability of the cavity to the female, he can only defend a restricted area.

The importance of cavities to the survival of winter-roosting birds has been studied by Moore (1945) and Kendeigh (1960). Because of cold temperatures, long periods of darkness, and the associated lack of energy intake during this time, nighttime is the critical peri for wintering birds. It is advantageous for overwinte ing birds to select winter roosts that are well insulat and retain heat.

Kendeigh (1960) noted that in order for birds winter in regions beyond their winter thermal rang they must be able to roost in cavities. This would particularly important for small birds, such as t pygmy nuthatch, in which the surface to volume ratio high. These birds utilize cavities as roost sites duri the winter and appear to select for those qualiti which reduce heat loss.

Keen (1955) found that snags between the ages o and 15 years fell very rapidly. This is consistent wi our finding. He also found that, after 25 years, o 10% of the snags were still standing. In contrast, aft 25 years, 40% were standing; and after 50 years, 25 of the snags were still standing in the ponderosa pi forest.

This study was designed to establish the relations between the quality and quantity of snags present the ponderosa pine forest of northern Arizona and t density and diversity of SCN's. Criteria for identifyi and preserving desirable snag trees are develop from the findings.

Study Areas

All areas used for this study (lats. 34°20′ – 35°16′ longs. 110°45′ – 111°48′ W., 1,981- to 2,256-m ele tion) are within the Coconino National Forest, Cocon County, Arizona, in the ponderosa pine vegetation ty Areas studied were the G. A. Pearson Natural Area the Fort Valley Experimental Forest; watersheds 8, 14, and 17, and the Monument Tanks study area in Beaver Creek Watershed; and Rocky Park and G Flat in the Woods Canyon Watershed. At the time this study, watersheds 8, 14, and 17 had recently b subjected to thinning treatments.

G. A. Pearson Natural Area

The G. A. Pearson Natural Area is 14.5 km northw of Flagstaff along U.S. Highway 180 (fig. 1). The 10 study area is on a south-facing slope within plot of the Fort Valley Experimental Forest. This area remained relatively untouched for the last 60 yea although a few snags have been removed by wood ters. During the study, the ponderosa pine density more than 7.6 cm was 489 trees per ha, with a foli volume of 49,658 m³ per ha. There were 5.2 sn per ha. There was no Gambel oak on this study p

Watershed 8

Watershed 8 is 64 km southeast of Flagstaff Forest Road 213 near Stoneman Lake (fig. 2). The 15 study area, on a west-facing slope of about 13°, is

Figure 1.—G. A. Pearson Natural Area. Note the dense thickets and snags.

Figure 2.—Watershed 8 study area. Note the snags and the openness due to treatment.

the southwest corner of the 729-ha watershed. Larson[3] and Szaro and Balda (1979) state that, after treatment, the ponderosa pine and Gambel oak densities were 216 and 20 trees per ha, respectively. The total foliage volume was 17,039 m^3 per ha. Ponderosa pine foliage volume was 14,169 m^3 per ha. During the 1975 breeding season, there were 1.5 snags per ha. In the late summer and fall of 1975, slash was piled and the number of snags reduced to 1.4 per ha.

Watershed 14

Watershed 14 is 68 km southeast of Flagstaff on Forest Road 230 (fig. 3). The study area is on a south-facing slope of about 9°. The 15-ha plot is in the southeast corner of the 221-ha watershed. Brown[4] and Szaro and Balda (1979) state that the ponderosa pine, Gambel oak, and alligator juniper densities after treatment were 145, 34, and 0.8 trees per ha, respectively. The total foliage volume was 6,526 m^3 per ha; whereas, ponderosa pine foliage volume was 4,382 m^3 per ha. The ponderosa pine snag density was 0.2 per ha.

Watershed 17

Watershed 17 is 43 km south of Flagstaff off Interstate Highway 17 on Forest Road 226. The 15-ha plot is on a southwest-facing slope of about 8°. The study area is in the southwest corner of the 49-ha watershed. Brown[5] and Szaro and Balda (1979) state that after the 1969 prescribed treatment, the ponderosa pine density was 59 trees per ha, and the Gambel oak density was 9 trees per ha. The total canopy volume and ponderosa pine foliage volume were 3,990 and 3,390 m^3 per ha, respectively. All snags had been removed during treatment.

Watershed 13

Watershed 13 is 66 km southeast of Flagstaff on Forest Road 230. The study area is on a southwest-facing slope of about 17°. The area was not treated before this study. Ponderosa pine density was 58[illegible] trees per ha. Gambel oak density was 54 trees per ha. The total foliage volume was 19,370 m^3 per ha, 16,437 m^3 of which was ponderosa pine. During the 3 years of this study, the density of snags remained at 3.2 per ha.

Monument Tanks

The Monument Tanks study area is 70 km southeast of Flagstaff on Forest Road 230 (fig. 4). The 15-ha plot faces west with a slope of approximately 12°. The area had not been treated since the mid-1940's. The ponderosa pine, Gambel oak, and alligator juniper densities were 350, 31, and 52 trees per ha, respectively.

[3]Larson, Frederick R. 1972. Watershed 8 treatment plan. Rocky Mountain Forest and Range Experiment Station. Flagstaff, Ariz. Unpublished.

[4]Brown, Harry E. 1969. Watershed 14 treatment plan. Rocky Mountain Forest and Range Experiment Station. Flagstaff, Ariz. Unpublished.

[5]Brown, Harry E. 1968. Watershed 17 treatment plan. Rocky Mountain Forest and Range Experiment Station. Flagstaff, Ariz. Unpublished.

Figure 3.—Watershed 14 study area. Note the open strip area and the lack of snags.

Figure 4.—Monument Tank study area. Note the short stunted growth and the snags.

The total foliage volume was 31,710 m^3 per ha; whereas, the ponderosa pine foliage volume was 15,697 m^3 per ha. The snag density was 3.7 per ha.

Rocky Park

The Rocky Park study area is 43 km south of Flagstaff on Forest Road 80 (fig. 5). The 12.5-ha plot is essentially flat. No prescribed treatment had been conducted on this area since the mid-1940's. The density of ponderosa pine was 460 trees per ha with a canopy volume of 56,163 m^3 per ha. Gambel oak density was 15 trees per ha. The total foliage volume was 58,003 m^3 per ha. During the 1977 breeding season, the snag density was 1.1 snags per ha; in 1978, the snag density was reduced to 1.0 per ha.

Gash Flat

The Gash Flat study area is 60 km southeast of Flagstaff on Forest Road 127 (fig. 6). The area is essentially flat. At the time of the study, no treatment of the area had occurred since 1947. The ponderosa pine and Gambel oak densities were 178 and 20 trees per ha, respectively. The total foliage volume was 50,187 m^3 per ha; whereas, the ponderosa pine foliage volume was 46,499 m^3 per ha. Snag density was 3.5 per ha during both breeding seasons.

Methods and Materials

Snags and Vegetation

In each of the study plots, the position of all snags greater than 6.1 m in height and greater than 30.5 cm in d.b.h. was mapped and numbered. The basal area and height were determined with a d.b.h. conversion tape and abney level, respectively.

The presence or absence of bark, the degree of decay of the wood, the presence or absence of small branches, and the presence or absence of large branches were recorded for each snag located on the G. A. Pearson Natural Area, and watersheds 8 and 14. Height of each cavity and the number of cavities per snag were also recorded on these areas.

During the winter and early spring of 1976, all snags on the G. A. Pearson Natural Area were surveyed. Since 1920, the vigor, condition, and time of death of all trees larger than 9.1 cm d.b.h. within this area have been recorded by the USDA Forest Service. Thus, the time of death for each tree, within a 5- to 10-year period, could be accurately established. A list was compiled of all the trees which died and the years in which they died. A field check was made to determine whether these snags were felled by natural causes or by cutting. Stumps or entire logs with roots exposed or entire logs apparently broken off were counted as snags fallen by natural

Figure 5.—Rocky Park study area. Note the open areas and the thickets.

Figure 6.—Gash Flat study area. Note the large trees and the open areas around the trees.

causes. In cases where a snag obviously had been cut, it was removed from the list. In addition, snags less than 25.4 cm d.b.h. were deleted because, in most cases, it was impossible to determine whether these trees had been cut or had fallen naturally.

Vegetation data used to determine absolute densities and foliage volumes were collected on all the study areas and analyzed using the procedures described by Szaro and Balda (1979).

Birds

Complete breeding bird censuses were made using the spot-map method (Kendeigh 1944). During the 1975 and 1976 breeding seasons, locations of individual birds and their nest sites were recorded for secondary cavity-nesting species on the G. A. Pearson Natural Area and watersheds 8 and 14. In addition, nest sites were recorded outside these three study plots in areas homogenous with the study plot. When a nest site was found, the following information was recorded:

1. D.b.h. of the tree containing the nest.
2. Height of cavity from ground.
3. Presence or absence of bark around cavity.
4. Estimate of the percent of bark on snag.
5. Presence or absence of a top on snag.
6. Total height of snag.

During the winter of 1975-1976, roost cavities were located for pygmy nuthatches in the G. A. Pearson Natural Area. The same series of data was collected for roost sites as was gathered for nest sites.

Species differences in mean d.b.h., mean height of cavity, and mean height of snag were tested using analysis of variance. The chi-square statistic ($P = 0.05$) was used to test species differences in the percentage of bark of snags used, the percentage of nests in snags, the percentage of nests with bark around the cavity entrance, and the percentage of nests in snags with a top present.

The effect of foliage volume and snag density on the density of breeding SCN's was examined using stepwise, multiple-linear regression. Factors used in this test were SCN density, snag density, total foliage volume, ponderosa pine foliage volume, and foliage volume contributed by other trees. Regression analysis was also used to determine the relationship between time and percentage of snags standing. Data on breeding densities of SCN's were gathered from eight study areas over a number of years by different workers. All studies used the same techniques to determine foliage volume, snag density, and breeding bird density.

The authors studied the G. A. Pearson Natural area and watersheds 8 and 14 in 1975 and 1976; and Gash Flat, Rocky Park, and Monument Tanks in 1977 and 1978. Szaro and Balda (1979) studied watershed 8 in 1974; watershed 14 in 1973 and 1974; and watersheds 13 and 17 in 1973, 1974, and 1975.

Results

Bird Populations

The number of species of SCN's fluctuated between three and eight and showed no overall trend with an increase in snag density. On all study plots, the average number of SCN species was six. This constitutes approximately 30% of the total bird species breeding on these areas. The relative proportion of the total population contributed by the SCN's showed a correlation (table 1) of $r = 0.78$ with snag density (fig. 7). This suggests that with more snags present, the SCN's make up proportionally more of the total population.

The highest absolute densities of SCN's occurred on the G. A. Pearson Natural Area, and the lowest on watershed 17 (table 2). A test of bird density against foliage volume and snag density resulted in a significant regression. The three independent variables chosen were snag density ($r = 0.74$), foliage volume of trees other than ponderosa pine ($r = -0.15$), and ponderosa pine foliage volume ($r = 0.72$). For the eight areas, 76% of the variability in bird densities was explained by these three independent variables ($P < 0.001$) (table 3).

Percentage of Nests in Snags

The percentage of nests placed in snags varied among the SCN's (table 4). The violet-green swallow showed a strong preference for snags, nesting exclusively in them. Both the pygmy nuthatch and the western bluebird also used snags as nest sites in high proportions, but shifted from snags to live pines or oaks in low snag density areas. The brown creeper utilized snags only for nest sites; whereas, the white-breasted nuthatch most often nested in live trees, especially in live oaks.

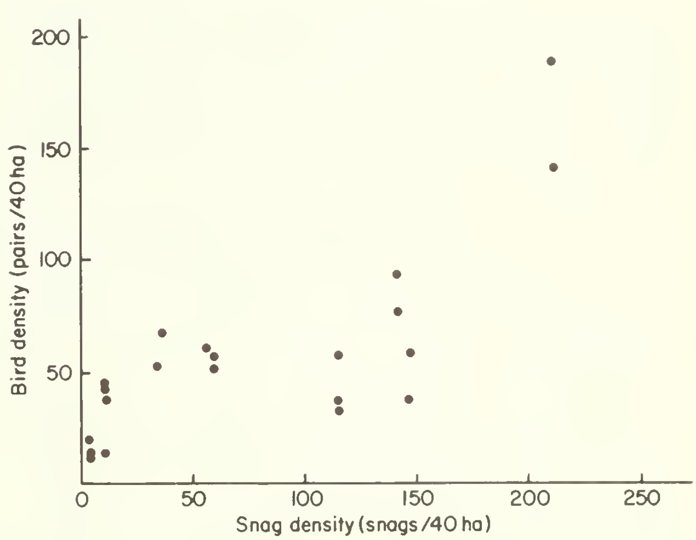

Figure 7.—The relationship between snag density and density of SCN's.

Table 1.—Breeding densities of SCN's per 40 ha

Study area	Years	Average number of snags	Average number (and percent) of species of SCN's	Total number (and percent) of pairs of SCN's
G. A. Pearson Natural Area	75-76	208	6 (32)	167 (55)
Monument Tanks	77-78	147	6 (30)	45 (45)
Gash Flat	77-78	141	6 (26)	85 (40)
Watershed 13	73-75	127	6 (37)	42 (45)
Watershed 8	74-76	58	7 (31)	56 (36)
Rocky Park	77-78	44	6 (31)	61 (37)
Watershed 14	73-76	11	5 (24)	34 (27)
Watershed 17	73-75	0	3 (21)	15 (20)

Table 2.—Average number of nesting pairs of SCN's (pairs per 40 ha)

Species	G. A. Pearson Natural Area	Gash Flat	Rocky Park	Monument Tanks	Watershed 8	Watershed 13	Watershed 14	Watershed 17
Violet-green swallow	45	19	18	6	10	9	2	0
Pygmy nuthatch	42	33	21	18	16	14	6	1
Western bluebird	26	16	9	6	12	5	12	6
Mountain chickadee	26	6	4	7	4	4	3	1
White-breasted nuthatch	12	7	6	6	9	6	9	7
Brown creeper	14	1	3	1	0	0	0	0
House wren	0	0	0	0	0	0	2	0
Western flycatcher	2	2	0	0	4	5	0	0
Flammulated owl	0	0	0	0	2	0	0	0
American kestrel	0	0	0	0	0	0	1	0
Total	167	84	61	44	57	43	35	15

Table 3.—Values for variables used in developing a regression model for SCN's

	Standard error	R^2	R^2change	F
Snag density	9.98×10^{-2}	0.54	0.54	16.66
Nonponderosa pine foliage volume	1.32×10^{-3}	.71	.17	6.08
Ponderosa pine foliage volume	3.39×10^{-4}	.76	.05	3.72

$DF_{regression} = 3$

$DF_{residual} = 17$

Regression equation:

$$y = 20.8 + 0.407x_1 - 3.27 \times 10^{-3}x_2 + 6.54 \times 10^{-4}x_3$$

Table 4.—Percentage of nests in snags

Species	Number of nests	Number (and percent) of nests in snags
Violet-green swallow	41	41 (100)
Pygmy nuthatch	34	30 (88)
Western bluebird	33	23 (70)
Mountain chickadee	8	5 (62)
White-breasted nuthatch	12	1 (8)
Brown creeper	4	4 (100)
House wren	2	0 (0)
Western flycatcher	1	0 (0)
Flammulated owl	1	1 (100)
Totals	144	105 (73)

Diameter of Selected Snags

Species differences in the d.b.h. of snags used for nest sites were examined using analysis of variance. The birds did not possess significantly different preferences for size of snag to use for nests. Ranges of d.b.h. for the several species show a considerable degree of overlap (table 5). Birds showed a strong preference for snags in the 60- to 70-cm-diameter class. Seventy-five percent of the nests were located in snags with a diameter greater than 60 cm.

Diameter class	Percent used
cm	
20-30	2
30-40	1
40-50	5
50-60	17
60-70	28
70-80	18
80-90	18
90-100	8
100-110	1
110-120	2

Height of Snags Selected

The birds selected snags with heights ranging from 2 to 36 m. Approximately 63% of all the snags used as nest sites were 20 m and taller.

Height classes	Percent used
m	
0-4	2
4-8	12
8-12	3
12-16	14
16-20	6
20-24	28
24-28	26
28-32	6
32-36	3

Bark Cover

The frequency of all nests in different bark classes was tested using chi-square. This test shows that nests of SCN's are found more frequently ($P<0.001$) in snags covered by bark than in snags with varying degrees of bark present (table 6).

Height of Cavity from the Ground

The mean height of cavities used by the birds was similar to the mean height of unused cavities on each study plot (table 7). This indicates that SCN's selected cavity heights in proportion to their availability. On the G. A. Pearson Natural Area, however, there appeared to be a slight trend for the use of the higher cavities.

Presence or Absence of Snag Tops

A high percentage of the snags used by SCN's had broken tops. There were broken tops on 66% of all the snags used as nest sites, but only 32% of all available snags were without tops. No species differences were evident, although, in most cases, the pygmy nuthatch utilized a higher percentage of broken-topped snags for nest sites than did the other species.

Presence of Bark Around the Cavity Entrance

All species appeared to prefer cavities with bark directly around the nest entrance. On the G. A. Pearson Natural Area, 98% of all the cavities used had bark encircling the entrance; on watersheds 8 and 14, the percentages were 82% and 100%, respectively. The percentage of all the available cavities with bark directly around the entrance was 58%.

Characteristics of Nest Sites in Oaks

Of the species which utilized oaks as alternative nesting sites, all selected nest sites in the larger-diameter trees (25.4-72.2 cm). There was a wide range in the height of cavities selected in oaks by SCN's (table 8).

Table 5.—Average d.b.h. of snags used by the birds of the ponderosa pine forest

Species	Number of nests	Mean d.b.h.	Standard deviation	Range of d.b.h.
	cm			
Violet-green swallow	41	75.1	15.0	52.1-114.6
Pygmy nuthatch	30	67.8	14.0	41.6-96.3
Western bluebird	23	67.6	19.3	29.5-114.6
Mountain chickadee	5	63.9	25.9	23.6-95.0
White-breasted nuthatch	1	72.6		
Brown creeper	4	87.0	16.5	69.6-102.9
Flammulated owl	1	64.0		
Totals	105	71.2	16.7	23.6-114.6

Table 6.—The different amounts of bark present around 105 nest holes

Species	Bark classes				
	0-20%	21-40%	41-60%	61-80%	81-100%
Violet-green swallow	4	1	8	8	20
Pygmy nuthatch	4	1	6	1	18
Western bluebird	1	1	2	4	15
Mountain chickadee	0	0	0	1	4
White-breasted nuthatch	0	0	0	0	1
Brown creeper	0	0	2	0	2
Flammulated owl	0	0	0	0	1
Total	9	3	18	14	61

Table 7.—Comparison of height (m) of cavities used and unused on three ponderosa pine forests

	Height					
	Used			Unused		
	N	Mean	Range	N	Mean	Range
G. A. Pearson Natural Area	72	18.2	2.4-29.3	189	15.7	4.2-27.4
Watershed 8	28	9.1	0.9-20.7	29	9.4	2.1-21.0
Watershed 14	10	8.6	2.1-19.8	4	7.0	3.3-8.8

Table 8.—Characteristics of all nest sites in oaks

Species	Number of nests	Mean diameter	Range	Mean height of cavity	Range
		cm		m	
Pygmy nuthatch	3	46.0	36.1-65.8	2.9	1.3-6.1
Western bluebird	9	35.6	25.4-65.0	3.7	1.2-7.9
Mountain chickadee	2	26.9	26.4-27.4	2.4	2.4-3.3
White-breasted nuthatch	9	37.7	28.4-43.7	2.6	1.5-6.4
House wren	1	38.1		4.6	
Western flycatcher	1	77.2		7.6	
American kestrel	1	32.8		3.6	
Total/means	26	38.4	25.4-77.2	3.3	1.2-7.9

Winter Roost Sites

Ten pygmy nuthatch winter roost sites were found on the G. A. Pearson Natural Area during the winter of 1975-1976. These were compared to 19 pygmy nuthatch nest sites located in the same area. No differences were found except that the mean height of roost cavities was 8 m lower than the mean height of the nesting sites.

	Means	
	Nest	Roost
Diameter of snags (cm)	72.3	74.7
Total height of snags (m)	23.8	22.1
Percent bark cover	74.6	89.7
Distance to nearest tree (m)	20.3	15.8
Height of cavity (m)	18.9	10.9
Percent with top off	68.4	70.0
Percent with bark around hole	100.0	100.0
n =	19	10

Snag Survival

The percentage of snags standing declined with time since tree death. After 10-15 years, approximately 30% of all snags had fallen. Slightly more than 50% of snags were standing after 20-25 years. Very few additional snags had fallen until 45-50 years had passed. At this point, 25% of the original snags were still standing.

Age classes	Number dead	Number cut	Number standing
years			*percent*
0-5	39	0	39 (100)
6-15	59	8	36 (71)
16-20	26	7	13 (68)
21-25	30	4	14 (54)
26-30	47	14	14 (42)
31-35	21	2	9 (47)
36-40	36	9	10 (37)
41-45	23	8	6 (40)
46-50	20	8	3 (25)

The loss of snags is more rapid at first and slows with time. The gradual decrease in attrition may be a result of sheltered snags. The regression equation explains 95% of the variability in percentage of snags standing ($P<0.005$) (fig. 8).

Snag Age Preference

SCN's preferred to nest in trees that had recently died. A significant number of nests were found in snags which had been dead less than 20 years (fig. 9). Within this age range, the birds used snags that were dead from 5 to 20 years more heavily than those dead for less than 5 years. If selection was based solely on snag availability, the number of nests located in the three youngest age classes should have been less than we found. Furthermore, assuming that snags accumulate cavities with time, a greater number of nests should be located in older snags if selection was based merely on availability.

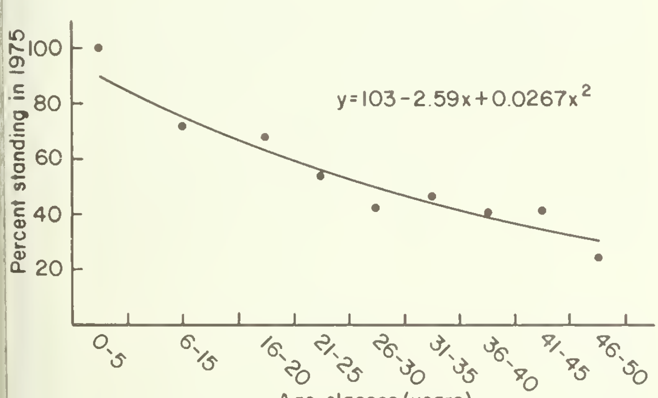

Figure 8.—Percentage of snags in nine age classes which were standing in 1975.

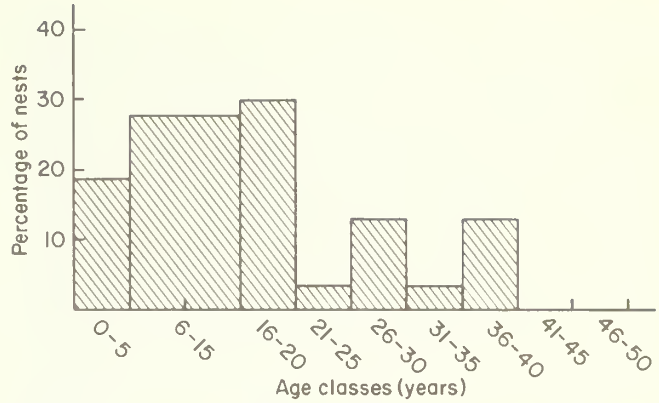

Figure 9.—Percentage of all nests within nine snag age classes.

Discussion

Diversity and Number of SCN's

Our findings are in essential agreement with other studies and support the idea that snag removal in a coniferous forest has a serious negative effect on the density of SCN's (fig. 9). Snag density alone explains more than half of the variability in density of SCN's (table 3). It is rather impressive that a single variable can explain such a high proportion of the variation. This is especially true considering that not all individuals nest in snags and that other environmental variables may also be important. For example, foliage volume of conifers probably represents a number of important niche dimensions such as quantity and quality of perches, food quantity (insects and seeds), territory size and quality, and shelter from weather and predators. These characteristics may be considered to allow survival in a coniferous forest, whereas, the snags allow reproduction there. This factor, although a significant one, contributed relatively little to the precision of the model once snags were accounted for.

Continuing research by the authors indicates that the year-to-year variability in breeding bird density of SCN's is low on areas of less than 60 snags per 40 ha and high at snag densities above 60. Other variables, perhaps winter and early spring low temperatures and snowfall amounts, are playing a different role at these higher snag densities.

The numbers of species of SCN's remained relatively constant between areas. Only when all snags had been removed (as in watershed 17) did a consistent reduction in the number of species occur. This was probably because of the loss of such snag-dependent species as violet-green swallow and brown creeper. Balda (1975) found seven species of SCN's breeding in areas where snags and oaks were present. He also found seven species in areas where snags were in low density and oaks were abundant. His findings are in agreement with this study.

In natural stands of ponderosa pine, it has been previously found that SCN's are 40-55% of the entire breeding bird population of the forest and 33% of the total breeding species (Balda 1975). The data collected from the G. A. Pearson Natural Area during this study support this conclusion. With reduced snag densities, however, the percentage of the total population contributed by the SCN's is reduced. In the G. A. Pearson Natural Area, the SCN's contributed more than one-half of the total breeding-bird density. When snags were reduced, the SCN's contributed less to the total population. Although all bird species in the forest declined in density, SCN's declined more sharply due to the shortage of available cavities. The result was a decline in the percentage of the total breeding population made up by the SCN's. No correlation existed between the number or diversity of SCN species on an area and the density of snags present. This was probably due to the small size of the study plots. Over broad expanses of pine forest, it seems reasonable to predict a change in species diversity with a change in snag density. The bird species found on the study plots were differentially affected by snag removal. The violet-green swallow, pygmy nuthatch, mountain chickadee, and brown creeper nested predominantly in snags.

In this study, the mountain chickadee was less restricted to snags than Balda (1975) thought. The violet-green swallow, pygmy nuthatch, and brown creeper appeared specific in where they nest, and would be most affected by snag removal. In contrast, the density of white-breasted nuthatchs may, in part, be controlled by oak density, since this species nested predominantly in oaks during two breeding seasons. The western bluebird showed a drastic switch in the percentage of nest sites placed in snags as snag density declined. This species appeared to generalize in nest site selection more than the above species. In addition, Conner and Adkisson (1974) found that eastern bluebirds prefer areas where clearcutting had occurred. Stripcutting watershed 14 may have made the habitat more suitable for the western bluebird, resulting in an increase in its density. In order of decreasing sensitivity to snag removal, the species segregate into four groups. The most sensitive species are the violet-green swallow and brown creeper which use snags exclusively. The mountain chickadee and pygmy nuthatch will use oaks or live pines if snags are drastically reduced. The western bluebird is much less sensitive than the above species to low snag densities and utilizes oaks extensively at low snag densities. Finally, the white-breasted nuthatch shows no sensitivity to the density of snags and uses cavities in live pines or oaks almost exclusively for nest sites.

The ability of some species to switch from snags to other sites for nesting could explain why these species inhabit forest lands devoid of snags. Switching may also be the reason we did not achieve greater precision with our regression equation. In ponderosa pine forests, however, oak cavities and suitable holes in live trees are rare, and the removal of snags will result in a decline in SCN's.

Characteristics of Nest Sites and Behavior of Birds

In groups of species which use a common resource (such as snags and cavities), ecological isolation is particularly orderly and precise in its definition (Cody 1974). This ecological isolation is achieved by the subdivision of the total resource range into what is called species resource spans. This allows each species to use a small portion of the entire available resource.

All species used the largest diameter and tallest snags available on all the study plots. This would account for the variation in the size of snags used between study plots. On the watershed plots where smaller-diameter, shorter snags were available, the birds used snags that were different from those on the G. A. Pearson Natural Area. McClelland and Frissell (1975) found that birds selected the largest diameter and tallest snags of both western larch and paper birch. Moore (1945) suggested that this selection may be due to a slower loss of heat through thick layers of dry rotting wood in larger trees. His work was primarily concerned with winter-roost sites of birds, but the same heat demands are probably present during the spring and summer breeding season at high altitudes.

Birds selected those snags with the greatest amount of bark. Our findings place the lower limit of greatest bird use at 60% bark cover. SCN's selection of trees with high percentages of bark cover may actually reflect selection made initially by primary cavity nesters. Personal observation indicates that snags with little or no bark are primarily snags which are called "hard snags." These have a high pitch content and rot slowly. Those snags which retain their bark are usually "soft snags" which are more easily excavated by primary cavity nesters. It is possible, therefore, that the SCN's did not select for percent bark cover, but rather for those snags with suitable cavities, which conceivably would be more abundant in "soft snags."

In all species which nested in snags, a high percentage of cavities were selected which were surrounded by bark. The percentage ranged from 77.8% to 100% for all three study plots. Many cavities present on the study plots were not surrounded by bark, and only a few of these were occupied. Martin (1963) found in laboratory tests that bark and wood were nearly equal in their ability to absorb heat. In addition, he found that the insulative properties of bark were much higher than wood of the same density.

Brown creepers nearly always built their nest sites behind loose bark. As bark generally remains longer on the lower portion of snags, the brown creeper selected cavities at considerably lower heights than the other four species. The other species tended to nest in the highest cavities available. This might reflect a tendency on the part of the birds to nest as high as possible to reduce predation and/or intercept maximum solar radiation.

McClelland and Frissell (1975) found that 78% of all active nests in western larch were in snags with broken tops. Heartrot proceeds at a faster rate in snags with broken tops (Hepting 1971, Partridge and Miller 1974). The development of the heartrot is necessary in many situations to allow primary cavity nesters to excavate cavities.

In this study, 68% of all snags used for nest sites had broken tops. This selection of broken-topped snags may reflect a greater number of cavities in such snags because woodpeckers are prone to excavate in them. Thus, large numbers of usable cavities would accumulate in these snags. SCN's would then be more apt to select a cavity in a snag without a top than one in a snag with a top because of the differential number of available cavities.

Norris (1958) noted that nuthatches, on occasion, excavate cavities for their own use, thus behaving at times as primary cavity nesters. Pygmy nuthatches were found in snags with a higher percentage of broken tops than other species. This preference for snags with broken tops may be related to the higher degree of decay making it easier for nuthatches to excavate cavities.

McClelland and Frissell (1975) found numerous nest sites in dead tops of live trees, and over 80% of these were in those whose tops were broken. In this study, only three nest sites were found in the dead tops of live trees. This was probably because of the low density of live trees with dead tops which were decayed enough or with a diameter large enough for primary cavity nesters to have excavated a cavity in them. The dead tops of most of the live trees were devoid of bark, appeared to be extremely hard, and had small diameter.

Characteristics of Nest Sites

Nest sites in live pines were similar to those in snags. This suggests that some of the same criteria are being used by the birds whether they are selecting a nest site in a snag or live pine. The only obvious deviation from this pattern occurred in terms of the percentage of nests with bark around the entrance of the cavity since they were all located in lightning scars. Only in regions on these live trees where the bark was gone and insects and fungi had attacked the tree was the wood suitable for excavation.

As with snags selected as nest sites, oaks used by the birds tended to be large-diameter oaks. This may again be related to heat retention of large-diameter trees, but possibly more important in oaks is the physical limitation of small-diameter trees. Only in the large-diameter oaks could a cavity be located which would be large enough for a nest site.

Characteristics of Winter-Roost Sites

Five of the eight principle SCN's in the ponderosa pine forest overwinter there. These five species are insectivorous and comprised between 63% and 73% of all winter residents (Balda 1975).

Pygmy nuthatches selected the largest and tallest snags for nest sites and winter-roost sites. This may be because of the greater heat retention in larger snags. Heat acquired during the brief daylight hours is retained longer in large-diameter snags than in small ones (Moore 1945). In addition, Moore also suggested that layers of dry rot frequently found in snags may further reduce heat loss by acting as insulation. Large-diameter snags might be expected to contain greater amounts of dry rot than small-diameter snags.

The roost sites located during this study were approximately 8 m lower in height than the nest sites. A lower cavity height would reduce the effect of wind blowing into and around the cavity. Kendeigh (1960) stressed the importance to roosting birds of reducing wind to lower convectional heat loss.

Moore (1945) indicated that birds lose less heat if they fit closely in the cavity, thereby reducing heat loss from the bird's body into the cavity space. During the winter of 1975-76, several pygmy nuthatches frequently roosted in the same cavity. This has a two-fold effect—allowing a better fit within the cavity and increasing heat production for the entire group.

Snag Survival

The data indicate the rate snags fall is rapid at first and slows with time. The data differ from Keen's (1955) findings, possibly because of climatic differences. Keen's study was done in California where the rainfall is greater than in northern Arizona. The rate of rotting may be higher in the more mesic area, and dry soil may also act as a better anchor for the dead roots than wet soil.

Snag Age Classes Used by Birds

The greater number of nest sites was found in the youngest three classes (20 years and younger). These younger snags have a greater percentage of bark cover present. Also, young snags are not as rotten as older ones, and the birds were observed to avoid nesting in snags which were extremely rotten.

Age of snag	Condition
years	
0-5	Needles still present Small branches present Bark all present
5-15	Small branches present 90-99% of bark present
15-20	Large branches present 80-90% of bark present

Younger snags contain a larger number of insects (Baker 1973, Keen 1955). To build a nest in a snag which could also serve as a foraging location could be energetically advantageous to those species which glean insects from the bark.

Pygmy nuthatches, however, did not follow the above trend. They selected a higher percentage of older snags than did the other species. Norris (1958) noted that pygmy nuthatches, on occasion, excavated their own cavities, but that the bird's skull construction and musculature are not well developed for excavation. It would then be to their advantage to select for excavation those snags which are pulpy and rotten. This could explain the common occurrence of pygmy nuthatch nest sites in snags of older age.

Additional Uses of Snags

Snags were used extensively by birds other than for nest or roost sites. The following are the other uses and the species involved:

Hawking posts.—Western bluebird, pygmy nuthatch, and violet-green swallow.

Singing or drumming posts.—Western bluebird, common flicker, gray-headed junco, hairy woodpecker, and northern three-toed woodpecker.

Feeding substrates.—Pygmy nuthatch, white-breasted nuthatch, brown creeper, hairy woodpecker, and northern three-toed woodpecker.

Perching and observation posts.—Violet-green swallow, western bluebird, and American kestrel.

The most frequently used snags were those which were tall and surrounded by few trees, thus providing the birds with a clear view of their surroundings. This was a particularly important characteristic for those species which used snags as territorial display posts and for predator detection. Those birds which used snags as a feeding substrate frequently selected snags which were recently dead (1-5 years) and had a high percentage of bark cover. Baker (1973) and Keen (1955) found that extensive populations of insect larvae invade recently dead trees. With time, the numbers of larvae drop off significantly. The peak in the number of insect larvae occurs about 2 years after the time of death of the trees.[6] This would suggest that birds are seeking out snags which are recently dead.

A Few Cautions

1. This study concentrated only on SCN's. Other animals, particularly mammals and insects, make heavy use of snags and must be considered in future studies.
2. Because of fire suppression practices, it is impossible to guess the number of snags standing in a pristine ponderosa pine forest. Most certainly there would be some, because wildfire creates as well as destroys snags.
3. This study views the avian community in the ponderosa pine forest as a stable one. The starling, an introduced SCN, is now invading the ponderosa pine forest, nesting in snags. If their populations continue to expand, they may become serious competitors with our native SCN's for suitable nesting sites.
4. Live trees designated as future snags in a snag recruitment program will provide two valuable resources needed by the SCN's—foliage volume for present use and suitable nest sites for the future.

[6] *Jackman, S. 1974. Some characteristics of cavity nesters: Can we ever leave enough snags? Paper presented to the Oregon Chapter of the Wildlife Society, January 1974.*

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Appendix

Flora List

Alligator juniper	*Juniperus deppeana*
Gambel oak	*Quercus gambelii*
Paper birch	*Betula papyrifera*
Ponderosa pine	*Pinus ponderosa*
Western larch	*Larix occidentalis*

Fauna List

American kestrel	*Falco sparverius*
Brown creeper	*Certhia familiaris*
Common flicker	*Colaptes auratus*
Eastern bluebird	*Sialia sialis*
Flammulated owl	*Otus flammeolus*
Gray-headed junco	*Junco caniceps*
Great tit	*Parus major*
Hairy woodpecker	*Picoides villosus*
House wren	*Troglodytes aedon*
Mountain chickadee	*Parus gambeli*
Northern three-toed woodpecker	*Picoides tridactylus*
Pied flycatcher	*Ficedula hypoleuca*
Pygmy nuthatch	*Sitta pygmaea*
Violet-green swallow	*Tachycineta thalassina*
Western bluebird	*Sialia mexicana*
Western flycatcher	*Empidonax difficilis*
White-breasted nuthatch	*Sitta carolinensis*

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Cunningham, James B., Russell P. Balda, and William S. Gaud. 1980. Selection and use of snags by secondary cavity-nesting birds of the ponderosa pine forest. USDA Forest Service Research Paper RM-222, 15 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

One factor limiting the population size of secondary cavity-nesting birds in ponderosa pine is the number of suitable nesting cavities. Snags in the pine forest provide a large number of species with nesting and roosting sites. To maintain secondary cavity nesters at their natural population level, a density of 5.2 snags per ha is recommended for mature pondersa pine.

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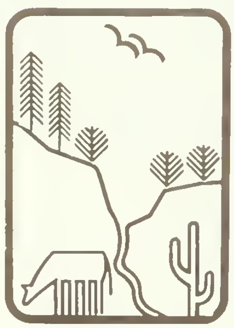
Rocky Mountains



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Rocky Mountain Forest and Range Experiment Station

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*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

Ponderosa Pine Provenances for the Northern Great Plains

James L. Van Deusen

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USDA Forest Service
Research Paper RM-223

September 1980

Ponderosa Pine Provenances for the Northern Great Plains

James L. Van Deusen, Research Forester
Rocky Mountain Forest and Range Experiment Station[1]

Abstract

Ponderosa pine trees representing 79 provenances were tested near Towner, N. Dak. Eight provenances can be recommended for planting in the northern Great Plains, based on 10 years in the plantation: 721 (Valentine, Nebr.); 720 (Ainsworth, Nebr.); 811 (Jordan, Mont.); (722 Chadron, Nebr.); 703 (Cave Hills, S. Dak.); 816 (York, Mont.); 704 (Slim Buttes, S. Dak.); and 757 (Rosebud, S. Dak.).

[1]Headquarters is at Fort Collins, in cooperation with Colorado State University. Research reported here was conducted at the Station's Research Work Unit at Bottineau, in cooperation with North Dakota State University, Bottineau Branch.

Ponderosa Pine Provenances for the Northern Great Plains

James L. Van Deusen

Management Implications

At least eight seed sources can be recommended for shelterbelt planting in the northern Great Plains. Nebraska sources 721, 720, and 722; South Dakota sources 703, 704, and 757; and Montana sources 811 and 816 have the combined height growth and survival capabilities needed for the northern Great Plains climate. They also were not damaged by source-specific attacks of insects, diseases, or animals. However, it is possible that, in the next 10 years, climatic extremes or other changes may cause slower growing sources to increase and presently fast-growing sources to decrease; or, the relatively low levels of biotic stresses may increase so much that changes are necessary in the sources recommended.

Trees at the original collection sites are believed to be standing and producing satisfactory cone crops at the usual seed crop frequency for ponderosa pine of 2-to 3-year intervals. Specific directions to the recommended provenances are on file.[2]

[2]Rocky Mountain Forest and Range Experiment Station, Shelterbelt Laboratory, First and Brander, Bottineau, N. Dak.

Introduction

Ponderosa pine (*Pinus ponderosa* Laws.) is one of the few conifers known to be adapted to the northern Great Plains. It has the largest native geographic range of pines in North America and is a conifer widely used in shelterbelts throughout the Great Plains. However, even the widely distributed ponderosa is not native to large portions of the Great Plains, and must be tested to determine its suitability for a variety of sites.

Conifer windbreaks help lessen the drying, chilling, and aggravating effects of the persistent winds. In addition, erosive soils are less likely to be blown away, and snow is more uniformly distributed when prairie winds do not sweep, unmodified, across the fields.

Tree improvement research in the Great Plains is striving to identify species and seed sources of trees that will grow well under Plains conditions. Ponderosa pine can help satisfy that need, but best suited seed sources have not been identified for the variety of growing conditions encountered throughout the Plains.

A comprehensive study[3] was designed to 1964 to: 1) find ponderosa pine seed sources best adapted for shelterbelt use in different regions of the Great Plains; 2) determine the range and distribution of genetic variation in the eastern range of ponderosa pine; and 3) provide plant material and data for progeny tests, seed orchard establishment, and breeding programs.

[3]Nienstaedt, Hans, and David H. Dawson. Study Work Plan: Ponderosa pine for the Great Plains Region. Document on file at Rocky Mountain Forest Range Experiment Station, Shelterbelt Laboratory, First and Brander, Bottineau, N. Dak.

Bulked seed samples from 79 sources (fig. 1 and table 1) were assembled by the Rocky Mountain Forest and Range Experiment Station's Bottineau, N. Dak., and Lincoln, Nebr. field units. Seeds came from 10 to 20 randomly selected trees growing at each collection site.

Plantations were established in 1968 and 1969 at 24 locations from Alberta and Saskatchewan, Canada, southward through the Plains to Oklahoma, and as far east as Pennsylvania.

Study Area

The North Dakota plantation was established in 1968, adjacent to the northern boundary of the State Forest Service Nursery at Towner, N. Dak., at an elevation of 1,480 feet (451 m). Average annual precipitation is 16.8 inches (427 mm), of which nearly 75% falls during the growing season. Average annual temperature is 39° F (4° C), but it can range from 100° F (38° C) to −40° F (−40° C). The soil at the planting site is a Sioux loamy sand on level to gently undulating land, covered by native grasses and weeds.

Methods and Materials

Seedlings for this plantation were grown to 2 + 1 age in the Towner Nursery. The plantation was established with 79 provenances, randomly arranged in each of 15 replications. Each replication consisted of 2 rows of 40

Figure 1.—Collection locations of ponderosa pine for the North Dakota provenance test (distribution map from Critchfield and Little 1966).

Table 1.—Provenance location data for ponderosa pine provenance test at Towner, N. Dak.

Geographical clusters and provenance number	Source data: Latitude	Source data: Longitude	Source data: Elevation
	°N	°W	m
Oregon, Washington, Idaho, and Montana Bitterroots			
865 OR	44.0	121 3	1,311
866 WA	48.3	111.9	488
867 ID	44.0	116.0	1,037
817 MT	47.0	113.8	1,037
818 MT	46.7	114.2	1,433
819 MT	45.9	114.2	1,250
820 MT	46.2	114.0	1,372
Transition			
816 MT	46.7	111.8	1,372
754 MT	47.1	110.9	1,387
753 MT	47.0	110.3	1,220
Central Montana			
815 MT	47.0	109.3	1,463
814 MT	47.0	109.0	1,128
813 MT	47.9	108.6	1,433
812 MT	47.5	109.5	1,037
821 MT	45.8	109.0	1,159
823 MT	46.1	107.4	884
829 WY	44.8	107.4	1,555
Central Rockies			
830 WY	44.7	107.1	2,134
831 WY	44.2	106.9	1,768
849 WY	42.8	105.1	1,585
848 WY	42.6	105.7	2,104
847 WY	42.3	105.3	1,677
857 WY	41.2	105.3	2,348
845 NE	41.5	104.0	1,555
844 NE	41.2	104.1	1,585
760 CO	40.2	105.6	2,561
761 CO	40.0	105.5	2,439
763 CO	39.1	105.1	2,378
764 CO	38.0	105.3	2,683
Southern Rockies and Plains			
765 CO	37.4	104.8	2,134
862 NM	37.0	104.3	2,241
863 NM	35.9	105.0	1,951
864 NM	35.5	105.3	1,951
766 NM	33.3	105.6	2,226
767 NM	33.0	105.4	1,951
768 NM	32.2	104.8	1,768
869 AZ	35.2	111.8	2,134
Low Elevation Eastern Plains			
855 NE	42.8	101.7	976
757 SD	43.3	101.0	793
721 NE	42.9	100.6	823
720 NE	42.7	99.8	701
856 NE	41.5	100.1	884
Central High Plains			
759 NE	41.5	103.1	1,310
758 NE	41.3	103.3	1,372
858 CO	40.6	105.2	1,616
859 CO	39.4	104.8	1,982
762 CO	39.4	103.8	1,799
724 CO	39.1	104.7	2,256
860 CO	38.6	105.0	1,982
861 CO	38.0	105.0	2,012
Black Hills and Northern Plains			
811 MT	47.6	107.0	884
822 MT	46.3	108.5	1,159
727 MT	46.9	105.2	808
826 MT	47.0	104.7	838
702 ND	47.0	103.5	762
701 ND	46.6	103.5	793
824 MT	46.0	106.6	1,037
825 MT	45.7	106.0	1,098
827 MT	45.9	104.5	1,159
828 MT	45.6	104.2	1,220
703 SD	45.9	103.5	976
704 SD	45.6	103.2	1,052
832 WY	45.0	105.6	1,189
833 WY	44.7	104.3	1,220
834 WY	44.5	104.5	1,677
835 WY	43.9	104.2	1,549
836 WY	43.7	104.1	1,244
837 SD	44.3	103.9	1,921
838 SD	44.0	103.7	1,732
839 SD	44.2	103.6	1,646
840 SD	43.8	103.4	1,280
850 WY	42.9	104.5	1,524
851 NE	42.7	103.6	1,280
846 WY	42.2	104.5	1,280
723 NE	41.8	103.9	1,402
722 NE	42.7	103.1	1,311
852 NE	42.6	102.5	1,159
853 NE	43.0	102.5	1,098
854 SD	43.3	101.8	1,006

rovenances each, or a total of 30 rows. Each plot had ur trees from one provenance, planted in a line. rees which died in the first year were replaced in pring 1969 from appropriate transplanted stock.

Rows 2 feet (61 cm) wide were tilled 12 feet (3.7 m) part, and were oriented generally north-south. The foot (61-cm) width adequately prepared the planting te, but native vegetation was not tilled between rows retain control of the erosive soil. Trees were achine-planted in May, spaced 8 feet (2.5 m) apart ithin rows.

Because grass and weed competition is detrimental to tree survival and growth in the Great Plains, competing vegetation was annually cultivated or sprayed with herbicides in bands adjacent to tree rows during the 10-year period. Weeds between tree rows were mowed annually. Simazine at 2 pounds (907 g) a.i. per acre was applied, generally in mixture with dalapon at 10 pounds (4.53 kg) a.i. per acre. To add nutrients to the sandy soil, a granular 23-23-0 fertilizer was scattered in a 3-foot (1-m) circle around each live tree in three of the last four years.

Results and Discussion

Survival

After the first three field seasons, survival was good, except for the southernmost provenances. But among those, even the New Mexican provenances were surviving at a rate of one tree out of three. Southern Rockies and Plains trees were killed probably by low winter temperatures rather than competition for soil moisture.

Survival by age 10 reflected the combined effects of low temperatures and soil moisture stresses. Source 703 from northwestern South Dakota had 85% survival, which was twice the plantation average. Ten provenances, however, had less than 10% survival after 10 years. Tenth-year survival for all sources ranged from 0% to 85% (table 2).

Although low winter temperatures may have been responsible for early mortality, competition for soil moisture was probably the most critical factor in survival. Despite the tilling, spraying, and mowing, some portions of the rooting zone of plantation trees probably had strong competition from weeds and grasses for soil moisture at all times. Because the soil at the plantation site has a poor moisture-holding capacity, survival and growth heavily depend on current precipitation. Four of the last five years had below-normal precipitation during the growing season, April through August. In 1976, precipitation for that period was 3.91 inches (9.9 cm) below normal; in 1977, it was 1.3 inches (3.3 cm) below normal.

Height

Tallest provenance was 721 NE (fig. 2a) which averaged 41 inches (104 cm), 50% taller than the plantation average (table 2). Height growth of all trees was not as good as expected; the plantation average of only 28 inches (70 cm) is equivalent to less than 3 inches (7 cm) per year (fig. 2b). Trees from the best provenance grew nearly 4 inches (10 cm) per year. Ponderosa pines at the nearby Denbigh Experimental Forest, on similar soils and from some of the same areas, have grown approximately 1 foot (30 cm) per year, for the past 40 years. Limited soil moisture, caused by grass and weed

a

Figure 2.—Two ponderosa pine trees after 10 growing seasons in the field. Tree in (a) is from the best provenance (721 NE), while the tree in (b) is from a North Dakota provenance (702), growing at approximately the average plantation rate.

Table 2.—North Dakota ponderosa pine provenance test; average survival and height growth for 79 provenances

Geographical clusters and provenance number	Survival 10-year	Tree height 10-year
	%	cm
Oregon, Washington, Idaho, and Montana Bitterroots		
865 OR	18	38
866 WA	10	44
867 ID	2	75
817 MT	10	77
818 MT	5	56
819 MT	25	48
820 MT	15	53
Transition		
816 MT	72	86
754 MT	77	81
753 MT	75	66
Central Montana		
815 MT	67	78
814 MT	63	77
813 MT	63	72
812 MT	55	72
821 MT	68	74
823 MT	58	80
829 WY	43	63
Central Rockies		
830 WY	47	65
831 WY	45	55
849 WY	57	53
848 WY	52	44
847 WY	12	69
857 WY	23	38
845 NE	38	57
844 NE	37	50
760 CO	43	51
761 CO	75	66
763 CO	70	79
764 CO	50	50
Southern Rockies and Plains		
765 CO	15	35
862 NM	2	15
863 NM	2	8
864 NM	0	0
766 NM	0	0
767 NM	0	0
768 NM	0	0
869 AZ	0	0
Low Elevation Eastern Plains		
855 NE	53	74
757 SD	62	98
721 NE	82	104
720 NE	72	98
856 NE	58	75
Central High Plains		
760 NE	55	60
758 NE	42	64
858 CO	38	51
859 CO	23	41
762 CO	63	58
724 CO	38	55
860 CO	18	34
861 CO	8	45
Black Hills and Northern Plains		
811 MT	82	90
822 MT	70	74
727 MT	70	86
826 MT	70	68
702 NE	57	68
701 ND	50	63
824 MT	60	80
825 MT	58	87
827 MT	57	72
828 MT	52	73
703 SD	85	79
704 SD	73	72
832 WY	43	58
833 WY	42	68
834 WY	45	74
835 WY	52	61
836 WY	58	65
837 SD	55	70
838 SD	60	69
839 SD	60	60
840 SD	42	59
850 WY	55	58
851 NE	50	57
846 WY	38	46
723 NE	68	75
722 NE	73	82
852 NE	45	65
853 NE	52	72
854 SD	43	59
Means	[1]42.4	[2]69.5

[1]*Survival percent transformed into arcsin $\sqrt{\%}$ for each provenance, then averaged for the plantation and converted back to percent.*

[2]*Weighted by number of surviving trees in each provenance.*

competition, probably reduced height growth for all provenances. Trees from the only two North Dakota provenances in the plantation (701, 702) grew at slightly less than the plantation average (table 2).

When height growth data at plantation ages 3, 5, and 10 were grouped into geographical clusters,[4] the clusters maintained their relative positions throughout the 10-year period (fig. 3). Height growth of provenances from the southern Rockies and Great Plains is distinctly inferior to other clusters.

Several of the tallest provenances at Towner also are among the tallest provenances at other planting sites (table 3). For example, provenances 721 NE, 720 NE, 757 SD, 811 MT, and 825 MT have been among the best growers in three to six other widely scattered plantations. It also offers encouragement that while trees at Towner generally are shorter than at other plantations, most of the best provenances at Towner have also been among the leaders elsewhere.

Geographical Clusters

When the provenances were grouped into geographical clusters, there were statistically significant differences in mean survival and height growth among clusters (table 4). No multiple range tests were made. Table 2 shows that most clusters have substantial performance variations among the included provenances.

Early Performance Indicators

If trees that will continue to be outstanding growers can be recognized from juvenile growth, substantial time can be saved in tree improvement. There was an excellent correlation between average tree height at plantation ages 5 and 10 for the 10 tallest provenances.

Table 3.—Number of provenances, from lists of the 10 tallest provenances at comparison plantations,[1] which were also among the 10 tallest at Towner, N. Dak.

Plantation location	Number of sources	Years of record
Phillipsburg, Pa.	4	9
Watertown, S. Dak	5	10
Alliance, Nebr.	4	10
Hastings, Nebr.	5	10
Junction City, Kans.	5	10
Norman, Okla.	5	10

[1] *First decade data in process of analysis by Ralph A. Read.*

[4] *Read, Ralph A. Genetic variation in seedling progeny of ponderosa pine provenances. Manuscript submitted to Forest Science Monograph in 1979.*

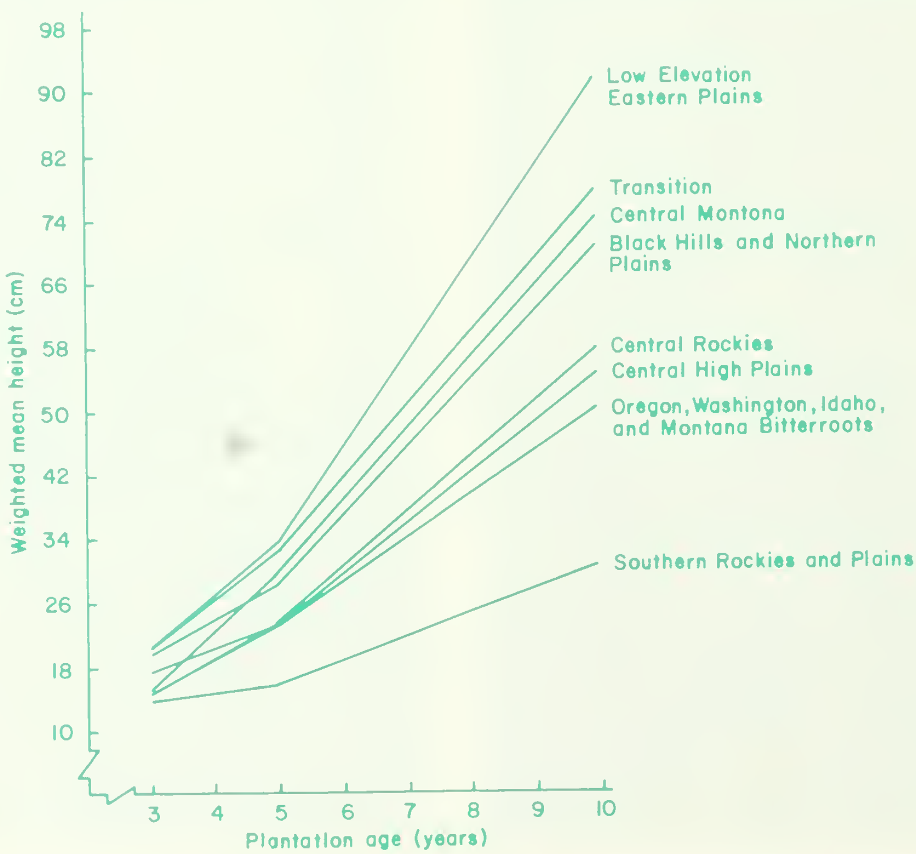

Figure 3.—Weighted mean height growth of eight geographical clusters of ponderosa pines at Towner, N. Dak.

Table 4.—Ten-year mean survival and height growth of eight cluster groups of ponderosa pine[1] provenances at Towner, N. Dak.

Geographical cluster	Means[2] Survival[3]	Height[4]
	%	cm
Transition	74	78
Low Elevation Eastern Plains	66	91
Central Montana	60	74
Black Hills and Northern Plains	58	71
Central Rockies	45	58
Central High Plains	35	54
Oregon, Washington, Idaho, and Montana Bitterroots	11	51
Southern Rockies and Plains	5	30
Plantation total and averages	42	70

[1]*The variety* scopulorum *is represented in all clusters except Oregon, Washington, Idaho, and Montana Bitterroots which is var.* ponderosa, *and Transition which is a transition between var.* scopulorum *and var.* ponderosa.

[2]*Analysis of variance indicated means differed significantly at the 1% level.*

[3]*Transformed into arcsin* $\sqrt{\%}$ *for provenances and converted back to percent for cluster averages.*

[4]*Weighted averages.*

The 10 tallest provenances, listed in order of decreasing mean height, are:

Age 5	Age 10
721	721
811	757
757	720
720	811
825	825
722	816
816	727
727	722
824	754
754	824

None of the changes at age 10 involve a shift of more han two positions. Relative ranking of all 79 proveances could not be predicted so well between ages 5 nd 10, but the leaders seemed to maintain their uperiority. The list of 10 tallest provenances does not nclude all the recommended provenances for seed colections because recommendations for seed collections ake survival into account as well as height growth. ome of the provenances with good survival grew lmost as fast as the 10 tallest.

ombining Traits

A single trait such as 10-year height growth or 0-year survival does not fully indicate performance. A ery few tall trees, or survival of many short ones, is ot enough to recommend those provenances as seed ollection areas. Fortunately, the best growing sources generally were also the ones with best survival and were not affected seriously by insects, diseases, or animals.

To decide which provenances to recommend for northern Great Plains plantings, a scheme suggested by Read[5] was used to combine the survival and height growth of provenances into a rank order. Four groups of six equal index classes (0-5) for survival and tree height were set up based on survival and height expressed as a percentage of the plantation mean. The average survival and height growth of each provenance, which had been calculated as a percentage of the plantation mean, was assigned to its appropriate index class. Then, the two indexes were summed for each provenance to make a total rating which combined relative survival and height growth.

For example, the range in percentages of the plantation mean for survival was 0% to 203%. Any provenance with a survival rate of 0% to 33% of the plantation mean was assigned an index of 0, while at the other extreme, those with a survival rate of 170% to 203% of the plantation mean, received an index rating of 5. Provenances 721 NE, 720 NE, and 811 MT rated 5 in each category, with a combined rating of 10 each.

To be recommended for northern Great Plains plantings, provenances must have a total rating of 9. Of all provenances rated, only eight were rated at 9 or 10: 721 (Valentine, Nebr.); 720 (Ainsworth, Nebr.); 811 (Jordan, Mont.); 722 (Chadron, Nebr.); 703 (Cave Hills, S. Dak.); 816 (York, Mont.); 704 (Slim Buttes, S. Dak.); and 757 (Rosebud, S. Dak.).

Mean survival and height growth of the eight leading sources was substantially better than plantation means. Mean survival for the leading sources was 73.9%, compared to the plantation mean of 42.4%. Mean height for the leading provenances was 90.1 cm; much higher than the plantation mean of 69.5 cm.

Winter Injury

Native and planted pines throughout the northern Great Plains suffered varying amounts of winter injury during the winter of 1978-79. Ponderosa pines probably were damaged more than other species. At Towner, N. Dak., injury to plantation trees ranged from insignificant browning of some needle tips to tree mortality.

During spring 1979, before winter injury symptoms had been obliterated by new growth, all live trees in the plantation were surveyed for winter damage.[6] The leading survivors and best growers were from provenances whose trees were least affected by winter injury. Provenance 721 NE had 26 trees with few or no injury symptoms. The next four most resistant provenances had only 40% as many injury-free trees: 727 MT and 811 MT (11 trees); 753 MT and 829 WY (10 trees).

[5]*Personal communication from Ralph A. Read. October 22, 1979.*

[6]*Personal communication from Richard Gilmore. North Dakota Forest Service.*

Biotic Stresses

No serious insect, disease, or animal damage has developed in the plantation. Damage from the western pine tip moth (*Rhyacionia bushnelli* Busck) has been of little consequence. The limited infestations that have been noted have been concentrated on the southern portions of the plantation, near existing rows of pole-size ponderosa pines that shelter the Towner Nursery. No provenance-related trends of infestation have appeared.

Common diseases such as the western gall rust (*Peridermium harknessii* J. P. Moore) are extremely rare in the plantation, even though gall rust is found in the vicinity.

Deer, porcupines, mice, or rabbits have made a minimum impact on plantation trees. Read (1971), however, reported preferences by jackrabbits for certain provenances in Nebraska.

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Read, Ralph A. 1971. Browsing preference by jackrabbits in a ponderosa pine provenance plantation. USDA Forest Service Research Note RM-186, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

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Van Deusen, James L. 1980. Ponderosa pine provenances for the northern Great Plains. USDA Forest Service Research Paper RM-223, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Ponderosa pine trees representing 79 provenances were tested near Towner, N. Dak. Eight provenances can be recommended for planting in the northern Great Plains based on 10 years in the plantation: 721 (Valentine, Nebr.); 720 (Ainsworth, Nebr.); 811 (Jordan, Mont.); 722 (Chadron, Nebr.); 703 (Cave Hills, S. Dak.); 816 (York, Mont.); 704 (Slim Buttes, S. Dak.); and 757 (Rosebud, S. Dak.).

Keywords: *Pinus ponderosa*, provenance test, shelterbelts

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Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
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Rocky Mountain Forest and Range Experiment Station

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Taxonomy and Effects of Dwarf Mistletoe on Bristlecone Pine on the San Francisco Peaks, Arizona

Robert L. Mathiasen and Frank G. Hawksworth

esearch Paper RM-224
ocky Mountain Forest and
ange Experiment Station
orest Service
.S. Department of Agriculture

Abstract

The dwarf mistletoe parasitizing bristlecone pine on the San Francisco Peaks, Arizona, is shown to be *Arceuthobium microcarpum*, instead of *A. cyanocarpum* as reported previously. The dwarf mistletoe causes serious localized damage, but it is not considered to be a serious threat to the bristlecone pine population.

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Research Paper RM-224

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Taxonomy and Effects of Dwarf Mistletoe on Bristlecone Pine on the San Francisco Peaks, Arizona[1]

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Department of Plant Pathology
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Rocky Mountain Forest and Range Experiment Station[2]

[1]This research is based, in part, on a Ph.D. dissertation accepted by the Department of Plant Pathology, University of Arizona, Tucson. The research was a cooperative effort between the University of Arizona and the Rocky Mountain Forest and Range Experiment Station.
[2]Headquarters is in Fort Collins, in cooperation with Colorado State University.

Contents

Taxonomy and Effects of Dwarf Mistletoe on Bristlecone Pine on the San Francisco Peaks, Arizona

Robert L. Mathiasen and Frank G. Hawksworth

Management Implications

Rocky Mountain bristlecone pine (*Pinus aristata* Engelm.) is found in many of the higher mountain ranges in Colorado and northern New Mexico. In Arizona, however, this species is found only on the San Francisco Peaks near Flagstaff. Bristlecone pine is the predominant species on only about 3,400 acres (1,360 ha) of the San Francisco Peaks. Bristlecone pine is considered as an endangered species in Arizona and, because of its rarity in the state, it is protected by the Arizona Native Plant Law (McDougall 1975).

A dwarf mistletoe parasitizing bristlecone pine on the San Francisco Peaks was discovered as early as 1901, but its taxonomic status, distribution, and impact on the bristlecone pine population there has remained uncertain. In 1973, we discovered a heavily mistletoe-infested bristlecone pine stand with considerable mortality on the south slopes of the San Francisco Peaks.

Morphological and physiological characteristics of the bristlecone pine dwarf mistletoe indicate it is *Arceuthobium microcarpum* (Engelm.) Hawksw. & Wiens. Only about 12% of the total area occupied by bristlecone pine on the San Francisco Peaks is infested. Noninfested bristlecone pine stands are now generally isolated from the infested stands by nonsusceptible species. In addition, *A. microcarpum* has an upper elevational limit well below that of bristlecone pine on the San Francisco Peaks and most of the bristlecone pine occurs above this limit. Therefore, although *A. microcarpum* is causing localized damage to bristlecone pine on the San Francisco Peaks, we do not consider the mistletoe to be a serious threat to this bristlecone pine population and do not consider control measures to be necessary.

Introduction

The classification of the dwarf mistletoe parasitizing bristlecone pine on the San Francisco Peaks, Arizona, has been uncertain since specimens were first collected by J. B. Leiberg in 1901. Gill (1935) classified the mistletoe as *Arceuthobium campylopodum* forma *cyanocarpum* (A. Nels.) Gill. Hawksworth and Wiens (1970, 1972) raised Gill's host form *cyanocarpum* to specific rank, based on its morphology, phenology, and host specificity. Hawksworth and Wiens (1972) tentatively identified the bristlecone pine dwarf mistletoe on the San Francisco Peaks as the limber pine dwarf mistletoe (*A. cyanocarpum* Coulter & Nelson), but noted that additional taxonomic studies were needed before a positive identification could be made. Comparison of the flavonoid constituents from shoots of the San Francisco Peaks bristlecone pine dwarf mistletoe with those of other species of *Arceuthobium* indicated the bristlecone pine dwarf mistletoe was most similar to the western spruce dwarf mistletoe (*A. microcarpum*) (Crawford and Hawksworth 1979).

Relatively little information on the effect of the San Francisco Peaks bristlecone pine dwarf mistletoe or its host range has been available until recently. The principal hosts of *A. cyanocarpum* are limber pine, whitebark pine, Great Basin bristlecone pine, and, rarely, Rocky Mountain bristlecone pine (Hawksworth and Wiens 1972). Hawksworth (1965) reported that bristlecone pine was the only host of the bristlecone pine dwarf mistletoe on the San Francisco Peaks, but Hawksworth and Wiens (1972) reported four additional hosts. Engelmann spruce and blue spruce were occasional hosts, and corkbark fir and southwestern white pine were rare hosts. It is now thought, however, that there is no blue spruce on the San Francisco Peaks and that the infected trees reported by Hawksworth and Wiens (1972) were somewhat aberrant Engelmann spruces.[3] Subsequent observations have failed to substantiate the report of blue spruce on the San Fran-

[3] *J. R. Jones, personal communication, 1976, formerly silviculturist, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Ariz.*

cisco Peaks, but indicated Engelmann spruce and bristlecone pine were more severely and commonly affected by the bristlecone pine dwarf mistletoe than originally believed.

Other dwarf mistletoes on the San Francisco Peaks are *A. douglasii* Engelm. on Douglas-fir and corkbark fir, *A. divaricatum* Engelm. on pinyon, *A. vaginatum* subsp. *cryptopodum* (Engelm.) Hawksw. & Wiens on ponderosa pine, and *A. microcarpum* on Engelmann spruce (Hawksworth and Wiens 1972). Bristlecone pine is also susceptible to *A. microcarpum* as demonstrated by artificial inoculations (Mathiasen 1978).

Study Objectives

This investigation was undertaken to clarify the taxonomic status of the bristlecone pine dwarf mistletoe, describe the distribution of the mistletoe on the San Francisco Peaks, identify the hosts of the mistletoe and their relative susceptibility, and determine the potential importance of the mistletoe to this local population of bristlecone pine.

Methods

Taxonomy

Morphological characters of the San Francisco Peaks' bristlecone pine dwarf mistletoe were compared with those of *A. cyanocarpum* and *A. microcarpum*. Measurements and observations of the bristlecone pine dwarf mistletoe were made from 19 specimens collected in 1975 from the San Francisco Peaks and from 5 specimens previously deposited at the USDA Forest Service, Forest Pathology Herbarium, Fort Collins, Colo. (FPF). Measurements of shoot height of *A. cyanocarpum* were made from 43 specimens collected throughout its geographic range. All other morphological data for *A. cyanocarpum* were taken from Hawksworth and Wiens (1972). Measurements and observations for *A. microcarpum* were made from 26 specimens collected throughout its geographic range in 1975 and 1976 and from 20 specimens previously deposited at FPF.

The following morphological characters were recorded: height, basal diameter, color, and growth habit of dominant male and female shoots (nonsystemic infections only); staminate flower diameter; number, length, width, and color of perianth lobes; length, width, color of the distal end, and length of the proximal end of mature fruit; and length, width, and color of mature seed. In addition, the northern (North Rim Grand Canyon, Kendrick Peak, and San Francisco Peaks, Arizona) and southern populations (White and Pinaleno Mountains, Arizona, and Mogollon Mountains, New Mexico) of *A. microcarpum* were analyzed separately.

Observations of flowering and seed dispersal were made in the summer and fall of 1973 through 1976 for the bristlecone pine dwarf mistletoe and *A. microcarpum* throughout their geographic ranges. The species of mistletoe, location, and date were recorded for each field observation, and flowering and seed dispersal were classed as not started, started but not near peak, near peak, past peak but not completed, or completed. Phenology data were summarized for all observations from July 1 through November 2. Results were compared with the flowering and seed dispersal periods of *A. cyanocarpum* (Hawksworth and Wiens 1972).

Since there are qualitative chemical differences among species of *Arceuthobium* (Hawksworth and Wiens 1972, Crawford and Hawksworth 1979), three collections of the bristlecone pine dwarf mistletoe, four collections of *A. microcarpum*, and one collection of *A. cyanocarpum* were analyzed chromatographically following the methods described by Hawksworth and Wiens (1972). All samples were analyzed in the first dimension only, and anthocyanins were not considered. Results were compared with those obtained for *A. cyanocarpum* and *A. microcarpum* by Hawksworth and Wiens (1972).

Distribution

The distribution of the bristlecone pine dwarf mistletoe was determined by reconnaissance surveys made in 1974 and 1975 of the larger and most of the smaller stands of bristlecone pine on the San Francisco Peaks. Kendrick Peak, approximately 15 miles to the west, was also examined for bristlecone pine. The approximate distribution of bristlecone pine and the geographic and elevational limits of the bristlecone pine dwarf mistletoe were recorded on topographic maps of the area (Humphrey's Peak and Sunset Crater West, Coconino County, Arizona, United States Geological Survey, 1966, 7.5 series). The approximate acreage of bristlecone pine and mistletoe-infested areas was estimated using a planimeter.

Hosts

Hawksworth and Wiens (1972) established five natural susceptibility classes based on the percentage of trees infected within 20 feet of heavily infected hosts of dwarf mistletoe. These were: principal (90% to 100%), secondary (50% to 90%), occasional (5% to 50%), rare (0% to 5%), and immune. General field observations for susceptible hosts of the bristlecone pine dwarf mistletoe were made on the San Francisco Peaks from 1973 through 1976. Specimens representing the different host-parasite combinations observed were collected and deposited at FPF.

In addition, all conifers over 4 inches d.b.h. were examined in 27 random 0.25- or 0.50-acre rectangular plots totaling 10 acres within the infested bristlecone pine stands on the San Francisco Peaks. the host species, dwarf mistletoe rating (DMR, 6-class system) (Hawksworth 1977), and condition (living or dead) of each tree were recorded. Observations were also made on an additional 13 randomly placed plots totaling 5 acres in noninfested bristlecone pine stands. Dead trees were randomly examined for signs of secondary pathogens and insects.

Damage

The effect of dwarf mistletoe on bristlecone pine on the San Francisco Peaks was assessed by comparing the mortality rates of infested and noninfested bristlecone pine stands. Mortality rates for bristlecone pine were also calculated on the basis of average plot mistletoe ratings for four mistletoe infection classes. Mistletoe-infested bristlecone pine acreage was also considered as a factor in assessing the effect of the dwarf mistletoe on the bristlecone pine population.

Results

Taxonomy

Analysis of morphological, physiological, and chemical characters of the bristlecone pine dwarf mistletoe indicate it is *A. microcarpum*, not *A. cyanocarpum*. Morphologically, the bristlecone pine dwarf mistletoe is most similar to *A. microcarpum* in shoot and fruit color, shoot height, fruit, flower, and seed size (table 1). Flowering and seed dispersal periods of the bristlecone pine dwarf mistletoe were approximately the same as those of *A. microcarpum*, while *A. cyanocarpum* flowers and disperses seed earlier (fig. 1). All three dwarf mistletoes were similar chromatographically, but *A. cyanocarpum* consistently lacked two flavonol bands present in both *A. microcarpum* and the bristlecone pine dwarf mistletoe.

Analysis of morphological and physiological characters of the northern and southern populations of *A. microcarpum* indicates differences between these

Table 1.—Comparison of morphological characters of the bristlecone pine dwarf mistletoe, *A. microcarpum* and *A. cyanocarpum*

Character	*A. microcarpum*[1]	Bristlecone pine dwarf mistletoe	*A. cyanocarpum*[2]
Mean shoot height (cm)	4	4	3
Mean shoot diameter (mm)	1.9	2.1	1.4
Mean fruit length (mm)	3.1	3.1	3.5
Mean staminate flower width (mm)	2.2	2.5	3.0
Mean seed length (mm)	2.4	2.4	2.0
Color (shoot distal end of fruit)	green to purple to brownish-green to reddish	green to purple to brownish-green to reddish	yellow-green to reddish-green

[1]*Northern population (see table 2).*
[2]*From Hawksworth and Wiens (1972).*

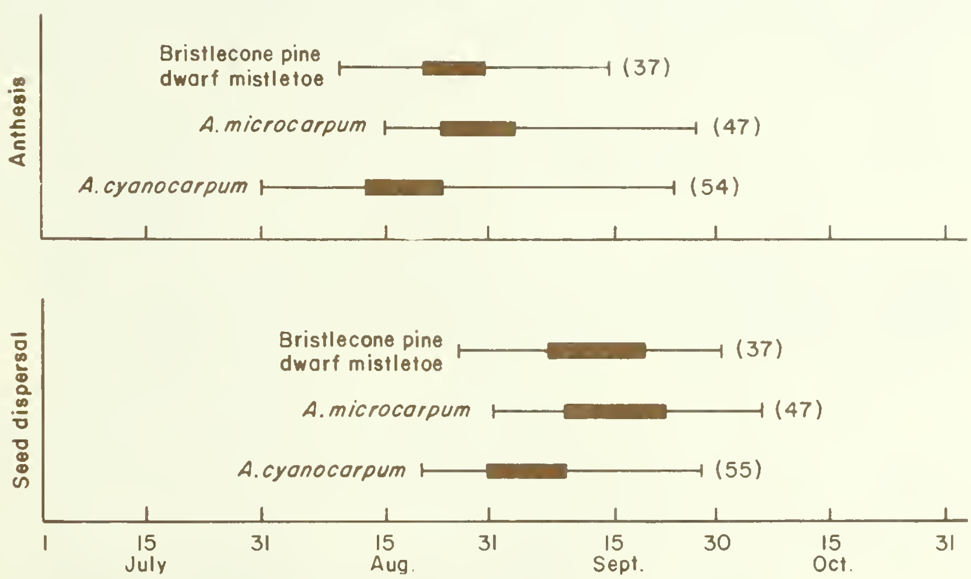

Figure 1.—Approximate periods of anthesis and seed dispersal of bristlecone pine dwarf mistletoe, *A. cyanocarpum* and *A. microcarpum*. Peak periods are shown by solid bars; number of observations are shown in parentheses.

populations (table 2). Shoots are larger in the southern populations and their flowering period occurs slightly later. Hawksworth and Wiens (1972) reported that southwestern white pine was immune to *A. microcarpum*. However, we found that *A. microcarpum* rarely parasitizes this tree on the San Francisco Peaks. Subsequent reconnaissance surveys in the southern populations of *A. microcarpum* did not detect infected southwestern white pines, although this tree is common in infested spruce stands.

Distribution

Our reconnaissance surveys indicate bristlecone pine is the predominant species on approximately 3,400 acres (1,360 ha) of the San Francisco Peaks (fig. 2). The tree is primarily distributed on the south side of the Peaks between 9,000 and 11,800 feet (2,700 and 3,600 m), and its main associates are Engelmann spruce and corkbark fir. Minor associates are Douglas-fir, southwestern white pine, quaking aspen, and very rarely, ponderosa pine and pinyon. Bristlecone pine was not found on Kendrick Peak.

Three populations of *A. microcarpum* were detected on bristlecone pine on the San Francisco Peaks (fig. 2). The largest population (approximately 350 acres) is near Schultz Peak (T. 22° N., R. 7° E., sec. 2, 3, 10, and 11) and contains large numbers of dead bristlecone pines (fig. 3). A second population (approximately 50 acres) is one-half mile due west of Schultz Peak (T. 22° N., R. 7° E., sec. 3 and 10), and is not continuous with the larger population. The third population consists of ten infected bristlecone pines in the Inner Basin approximately 1.5 miles (2 km) north of Schultz Peak (T. 23° N., R. 7° E., sec. 27). The 10 trees are close to Engelmann spruces heavily infected with *A. microcarpum*. Thus, about 400 acres (160 ha) or 12% of the total area dominated by bristlecone pine on the San Francisco Peaks, is affected by dwarf mistletoe.

A. microcarpum occurs as low as 9,100 feet (2,700 m) and as high as 10,300 feet (3,100 m) on ridges running southeast and north from Schultz Peak, respectively (fig. 2). It does not extend above 10,300 feet near Schultz Peak or in the Inner Basin, although bristlecone pine and Engelmann spruce occur continuously to higher elevations in both of these areas.

Hosts

Bristlecone pine is the principal host of *A. microcarpum* in the infested stands near Schultz Peak. Engelmann spruce is also parasitized by *A. microcarpum* in the vicinity of Schultz Peak, but not as severely as bristlecone pine. The following infection percentages were obtained from the 27 plots placed in the infested bristlecone pine stands around Schultz Peak:

Tree species	Number of trees examined	Percent infected
Bristlecone pine	1,404	84
Engelmann spruce	608	32
Corkbark fir	185	5
Southwestern white pine	317	1
Douglas-fir	87	0
Pinyon	5	0

Observations in the Schultz Peak area indicate approximately 50% to 80% of the Engelmann spruce near heavily infected bristlecone pines are infected. Therefore, Engelmann spruce is classified as a secondary host of *A. microcarpum* in that area. Infection levels are much higher for Engelmann spruce in the Inner Basin where spruce is the principal host of *A. microcarpum*. Differences in host response were observed for infected Engelmann spruce in the two different areas also. In the Schultz Peak area, witches'

Table 2.—Comparison of the northern and southern populations of *A. microcarpum*

Character	Northern population[1]		Southern population[2]	
Number of specimens examined	37		20	
Shoot height, mean and range (cm)				
Pistillate	3.9	3.0-7.0	6.6	4.0-12.0
Staminate	3.2	1.5-7.0	5.8	3.0-13.0
Basal diameter mean and range (mm)	1.5	0.8-2.4	2.0	1.0-3.0
Principal hosts	Bristlecone pine Engelmann spruce Blue spruce		Engelmann spruce Blue spruce	
Rare hosts	Southwestern white pine Corkbark fir		Corkbark fir	
Immune species	White fir Ponderosa pine Douglas-fir Subalpine fir		White fir Ponderosa pine Douglas-fir Southwestern white pine	

[1] *North Rim, Grand Canyon; Kendrick Peak and San Francisco Peaks, Arizona.*
[2] *White Mountains and Pinaleno Mountains, Arizona, and Mogollon Mountains, New Mexico.*

Figure 2.—Approximate distribution of bristlecone pine *A. microcarpum*, and the bristlecone pine dwarf mistletoe on the San Francisco Peaks, Arizona. Areas encircled by dark lines represent bristlecone pine. Checkered areas (1 to 3) represent the bristlecone pine dwarf mistletoe. Crossed area (4) represents *A. microcarpum* on spruce with scattered populations of healthy bristlecone pine.

brooms are generally dense and round with unusually large stem swellings. In the Inner Basin and elsewhere, witches' brooms are commonly "flat" and less dense without large branch swellings.

Southwestern white pine and corkbark fir are rare hosts of *A. microcarpum* near Schultz Peak, but frequent observations of these species in the infested Inner Basin stands did not detect infected trees. Of several hundred trees examined for *A. microcarpum* (near Schultz Peak), only 11 infected southwestern white pines and 12 infected corkbark firs were discovered. Abundant shoot production is characteristic of infections on bristlecone pine (fig. 4), but few shoots are produced on infected southwestern white pines and corkbark firs (figs. 5 and 6). Small, nonsystemic witches' brooms and abnormally large stem swellings result from infection by *A. microcarpum* on both of these rare hosts.

Figure 3.—Bristlecone pine mortality resulting from infection by *A. microcarpum* on the San Francisco Peaks.

Figure 4.—Shoots of *A. microcarpum* on bristlecone pine (pistillate shoots).

Figure 5.—*A. microcarpum* on corkbark fir, a rare host. Note the large fusiform swelling and poor shoot production.

Figure 6.—*A. microcarpum* on southwestern white pine, a rare host.

Douglas-fir is immune to *A. microcarpum;* no infected Douglas-firs were found among heavily infected bristlecone pines. A few infected Douglas-firs were found near Schultz Peak, but examination of the mistletoe on these trees indicated that they were infected by *A. douglasii* (Hawksworth and Wiens 1972). A few trees each of white fir, ponderosa pine, and pinyon were observed near heavily infected bristlecone pines, but none were infected.

Damage

Mortality counts indicate that approximately 37% of the standing bristlecone pines are dead in the dwarf mistletoe infested areas near Schultz Peak. Most of the dead bristlecone pines had large witches' brooms indicative of mistletoe infection (fig. 7). No other primary pathogens or insects were detected in the dead trees. Mortality of bristlecone pine in the noninfested areas sampled was one-sixth of that in the mistletoe-infested stands. Mortality rates of bristlecone pine were also calculated on the basis of average plot mistletoe ratings for four mistletoe infection classes as a percentage of the total number of standing trees examined. The results show that mortality is related to the severity of mistletoe infection:

Figure 7.—A dead, heavily mistletoe-infected bristlecone pine.

Level of infection	Bristlecone pine mortality
Stand basis	*percent*
Noninfested (DMR 0)	4.7
Lightly infested (DMR 0.1-2.0)	3.0
Moderately infested (DMR 2.1-4.0)	25.2
Heavily infested (DMR 4.1-6.0)	40.6

Discussion

Results of analysis of morphological, physiological, and chemical characters of the San Francisco Peaks bristlecone pine dwarf mistletoe indicate it is *A. microcarpum*, and not *A. cyanocarpum* as suggested by Hawksworth and Wiens (1972). The susceptibility of bristlecone pine to *A. microcarpum* as demonstrated in artificial inoculation trials (Mathiasen 1978) and Crawford and Hawksworth's (1979) comparison of flavonoid compounds found in dwarf mistletoe shoots also supports the classification of the bristlecone pine dwarf mistletoe as *A. microcarpum*.

Ecological evidence also lends support to the classification of the San Francisco Peaks bristlecone pine dwarf mistletoe as *A. microcarpum*. The upper elevational limit of the mistletoe on the San Francisco Peaks is the same as that reported for *A. microcarpum* in the White Mountains, Arizona (Acciavatti and Weiss 1974). The reasons for a distinct elevational limit are unclear, but are probably climatic. Hawksworth (1956, 1969) reported an upper elevational limit for the lodgepole pine dwarf mistletoe (*A. americanum* Nutt. ex Engelm.) which was several hundred feet below the upper elevational limit of its principal host in the central Rocky Mountains. Hawksworth (1969) suggested that fruits of *A. americanum* may not mature at elevations above its natural limits because of the shortness of the growing season. A similar situation may be responsible for the absence of *A. microcarpum* above 10,400 feet (3,700 m) in Arizona and possible for its absence from the extensive stands of Engelmann spruce in the central and northern Rocky Mountains.

Morphological and physiological differences between the southern and northern populations of *A. microcarpum* may represent genetic variation, or the influence of environmental and/or host variation. Latitudinal and/or elevational differences may be influencing both shoot height and flowering in these populations. Although the differences between these populations appear to be geographically consistent, we do not believe they are of the magnitude to warrant taxonomic recognition.

A. microcarpum parasitizes bristlecone pine and Engelmann spruce as principal hosts on the San Francisco Peaks and rarely parasitizes southwestern white pine and corkbark fir there. This is the only reported case of one species of dwarf mistletoe parasitizing four different hosts at a single location. Also, this is only the second reported case in North america of a dwarf mistletoe parasitizing members of two genera as principal hosts (Hawksworth and Wiens 1972, Wass 1976, Smith and Wass 1976).

The differences in host susceptibility and host response between the Schultz Peak population and other populations of *A. microcarpum* may indicate the Schultz Peak population represents a different physiological race. Engelmann and blue spruce are the principal hosts of *A. microcarpum* throughout most of its geographic range. However, bristlecone pine is the principal host of *A. microcarpum* around Schultz Peak, and infection of Engelmann spruce in this area is considerably less than in other localities. Mortality rates for Engelmann spruce are low in the Schultz Peak area and its response to infection is abnormal. Infection of corkbark fir by *A. microcarpum* is known from other localities in Arizona (Gill 1935, ([4])), but infection of southwestern white pine is known only from the Schultz Peak area. Further studies are needed, however, to determine if these differences in host responses and susceptibility have taxonomic significance.

The damage to bristlecone pine caused by *A. microcarpum* on the San Francisco Peaks is very localized. Bristlecone pine mortality is considerably greater in the mistletoe-infested stands when compared to noninfested stands, but the infested areas represent a low percentage of the total acreage dominated by bristlecone pine on the Peaks. The likelihood of *A. microcarpum* spreading into presently noninfested bristlecone pine stands is low because most of these stands are distributed above the upper elevational limits of the mistletoe and because the stands below the limit are separated from the infested stands by areas dominated by nonsusceptible species creating natural buffer zones. Therefore, *A. microcarpum* does not represent a serious threat to the bristlecone pine stands on the San Francisco Peaks, and management plans for bristlecone pine on the Peaks do not need to include control of *A. microcarpum*.

[4] *R. L. Mathiasen, unpublished data.*

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Appendix

Common and Scientific Names of Trees

Aspen	*Populus tremuloides* Michx.
Blue spruce	*Picea pungens* Engelm.
Bristlecone pine[1]	
Rocky Mountain	*Pinus aristata* Engelm.
Great Basin	*Pinus longaeva* D. K. Bailey
Corkbark fir	*Abies lasiocarpa* var. *arizonica* (Merr.) Lemm.
Douglas-fir, Rocky Mountain	*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco
Engelmann spruce	*Picea engelmannii* Parry
Limber pine	*Pinus flexilis* James
Lodgepole pine	*Pinus contorta* Dougl.
Pinyon	*Pinus edulis* Engelm.
Ponderosa pine, Rocky Mountain	*Pinus ponderosa* var. *scopulorum* Engelm.
Southwestern white pine	*Pinus strobiformis* Engelm.
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt. var. *lasiocarpa*
White fir	*Abies concolor* (Gord. et Glend.) Lindl.
Whitebark pine	*Pinus albicaulis* Engelm.

[1]*Unless stated otherwise, bristlecone pine as used in this paper refers to* Pinus aristata.

Mathiasen, Robert L., and Frank G. Hawksworth. 1980. Taxonomy and effects of dwarf mistletoe on bristlecone pine on the San Francisco Peaks, Arizona. USDA Forest Service Research Paper RM-224, 10 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

The dwarf mistletoe parasitizing bristlecone pine on the San Francisco Peaks, Arizona, is shown to be *Arceuthobium microcarpum* instead of *A. cyanocarpum* as reported previously. The dwarf mistletoe causes localized damage on the San Francisco Peaks, but it is not considered to be a serious threat to the bristlecone pine population.

Keywords: Engelmann spruce, *Arceuthobium cyanocarpum*, *Arceuthobium microcarpum*

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Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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Management of Ponderosa Pine in Even-Aged Stands in the Southwest

Robert R. Alexander and
Carleton B. Edminster

Research Paper RM-225
Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture

Abstract

Potential production of ponderosa pine in the Southwest is simulated for various combinations of stand density, site index, age, and thinning schedule. Such estimates are needed to project future development of stands managed in different ways.

Plant a tree! Mark the 75th birthday of the Forest Service by giving a living gift to future generations.

Cover Photo.—Second-growth ponderosa pine on site index 60 lands (Meyer 1961) thinned to a GSL of 80, Taylor Woods near Flagstaff, Ariz. Stand was about 45-years old when thinned in 1962.

USDA Forest Service
Research Paper RM-225

December 1980

Management of Ponderosa Pine in Even-Aged Stands in the Southwest

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Contents

Management of Ponderosa Pine in Even-Aged Stands in the Southwest

Robert R. Alexander and Carleton B. Edminster

Silviculture of Southwestern Ponderosa Pine

Southwestern ponderosa pine[2] (*Pinus ponderosa* Laws) cover type occupies the largest area of commercial forest land in Arizona and New Mexico (Choate 1966, Spencer 1966). It is less extensive in southwestern Colorado and southern Utah (Choate 1965, Miller and Choate 1964). Ponderosa pine forests in the Southwest occur between 6,000 and 8,500 feet elevation, but reach maximum development between 7,000 and 7,800 feet, where they are the climax forests (Schubert 1974).

Southwestern ponderosa pine forests were first cut during the Gold Rush of the mid-1800's. Commercial cutting began with construction of the transcontinental railroad during the late 1800's. Since then, ponderosa pine forests have provided a variety of wood products, forage for livestock, and habitat for a variety of wildlife. Today other uses are becoming important.

How these forests are managed affects all resources and uses. For example, if timber production is the primary objective, higher growing stock levels (GSL)[3] should be maintained, but forage production and water yields can be substantially increased only at lower GSL's. Low to medium GSL's are generally considered necessary to improve developed recreational opportunities and enhance foreground esthetics. Wildlife habitat varies from uncut to open forests. Improvement of middleground and background esthetics generally requires a combination of open, low stocking and high stocking levels that provide contrasts.

Although land managers must increasingly direct their practices toward multiple uses, these practices must be based on sound silvicultural principles of the forest type involved. Land managers must understand the tradeoffs between the timber resource and other physical, social, and economic considerations.

In the past, southwestern ponderosa pine has been under extensive management. Harvesting practices have generally been limited to "loggers selection" or sanitation salvage and improvement selection cutting that removed trees in a series of cuts on an individual or group basis. Cutover areas were allowed to restock naturally regardless of the time required or the stocking achieved. Today, management intensity has increased, and managers are concerned with (1) prompt restocking of cutover areas with a new stand, (2) increasing the growth rate of the new stand by control of stand density, and (3) improving quantity and quality of yields by periodic thinning to maintain stocking control and growth rates and reduce mortality.

In old growth stands, average annual net increment varies from 25 to 90 fbm per acre because of understocking or overstocking and high mortality associated with old-growth timber (Pearson 1950). Under intensive even-aged management, annual net growth can be increased to 100 to 300 fbm per acre (Edminster 1978).

Stand density control offers the greatest opportunity for increasing wood production by increasing growth and reducing mortality, but harvested stands must be replaced promptly to reduce time required to reach maximum yields. Ponderosa pine regeneration in the Southwest has been notoriously slow, and some areas have remained unstocked or poorly stocked for 50 years or longer. Periods of 10 to 30 years are more common, but they still are not compatible with rotations of 80 to 120 years. Low stumpage values have also hindered intensive management. Improving stumpage values and better understanding of natural and/or artificial regeneration allows forest managers to do the cultural work necessary to increase timber production.

Establishment of Regeneration

Southwestern ponderosa pine forests can be maintained as productive forests under an even-aged management system. A two-cut shelterwood method is most appropriate for converting even-aged, old-growth stands to managed even-aged stands (Schubert 1973). Uneven-aged, old-growth stands require at least a three-cut shelterwood that may incorporate features of sanitation-salvage and improvement selection methods for conversion to managed, even-aged stands. An uneven-aged management system which includes individual tree selection and group selection cutting methods is also appropriate for use in ponderosa pine stands. They are not discussed in this paper because suitable growth and yield prediction tools are not available for managed, uneven-aged stands.

[2]Southwestern ponderosa pine as described here does not include the Front Range of Colorado and Wyoming.

[3]Growing stock level (GSL) is defined as the residual square feet of basal area when average stand diameter is 10 inches d.b.h. or more. Basal area retained in a stand with an average diameter of less than 10 inches is less than the designated level (Myers 1971, Edminster 1978). Tables A-1, A-2, and A-3 in the appendix give the basal area, number of trees, and square spacing in stands with average diameters after thinning of 2 to 10 inches, for GSL levels 40 to 160.

Natural regeneration of ponderosa pine will be slow to establish and poorly distributed under any cutting method if any of the following requirements are not met (Schubert 1974):

1. A large supply of viable seed.
2. A well prepared seedbed.
3. A site free of competing vegetation.
4. A low population of seed-eating animals.
5. Sufficient soil moisture.
6. Protection from trampling and browsing and certain insects.

If cutover stands remain unstocked or poorly stocked more than 5 years after final harvest, the manager must take action under the regulations of the National Forest Management Act of 1976 to artificially regenerate the areas. Schubert (1974) summarized guidelines for planting and direct seeding of southwestern ponderosa pine.

Schubert (1974) recommends planting at least 680 trees per acre. This should provide a stocking of 340 trees per acre when average stand diameter reaches 5 inches d.b.h., which is GSL 80. However, if ponderosa pine is to be managed at higher GSL's, a minimum of 1,000 to 1,200 trees per acre should be planted.

Need for Early Precommercial Thinning

Establishing a new stand is only the beginning. Trees must have room to grow to reach merchantable size in a reasonable amount of time. Where ponderosa pine has regenerated well naturally in the Southwest, reproduction is often overly dense—the 1919 seedling crop is a notable example. At Taylor Woods, on the Fort Valley Experimental Forest in Arizona, stands with an average of 5,800 stems per acre reached an average stand diameter of 2.6 inches in 43 years, and more than one-third of a 120-year rotation has passed without any usable wood production (Schubert 1971). For acceptable growth rates, precommercial thinning is needed to reduce stand density to 1,000 to 1,200 stems per acre before age 10 years.

When adequate numbers of well distributed seedlings become established within 5 years after the seed-cut of a shelterwood method, the removal cut should be made promptly to avoid suppression. In stands infested with dwarf mistletoe, the longer the overwood remains in place, the greater is the probability of transmitting the parasite to the new stand.

Estimates of Growth Under Intensive Management

Intensive management of southwestern ponderosa pine forests provides many opportunities for increasing usable wood production, but estimates of future stand development under various management regimes are needed.

Information available on the growth of ponderosa pine from sapling stage to final harvest under even-aged management with a shelterwood cut is provided by field and computer simulation procedures developed by Myers (1971) and Myers et al. (1976) and refined by Edminster (1978). The procedures were developed from field data on past growth as related to stand density, age, and site quality.

The modeling concept used in these programs holds that the whole stand is the primary model unit, characterized by average values. The equations upon which the growth and yield simulations are based are given in Myers et al. (1976). The programs project stand development by consecutive, 10-year periods and include relationships to project average stand diameter, average dominant and codominant height, and number of trees per acre. Average diameter at the end of a projection period is a function of average diameter at the beginning of the period, site index, and basal area per acre. Periodic average dominant and codominant height growth at managed stand densities is a function of age and site index. Periodic mortality is a function of average diameter and basal area per acre. Adjustments are made to the growth and mortality functions to account for the effects of dwarf mistletoe infestation. Stand volume equations are used to compute total cubic feet per acre; factors are computed to convert this to merchantable cubic feet and board feet. Prediction equations are included to estimate the effects of differing intensities of thinning from above and below on average diameter, average dominant and codominant height, trees retained per acre, and average dwarf mistletoe rating (Hawksworth 1977).

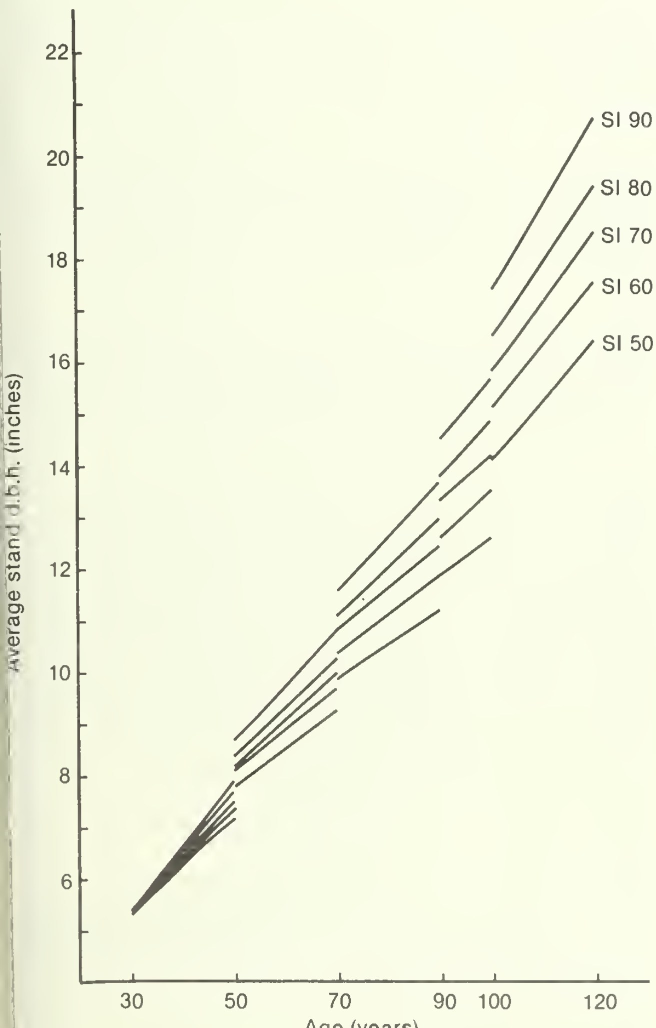
Yield simulations discussed in the following paragraphs were made to the same hypothetical initial stand conditions for all growth parameters:

1. Average total age at first thinning is 30 years.
2. Average stand diameter is 4.5 inches d.b.h.[4]
3. Stand density is 1,000 trees per acre.
4. Site index is 50, 60, 70, 80, and 90 at base age 100 years (Meyer 1961).
5. Dwarf mistletoe rating is 0.
6. Projections were made for 50 years (stand age 80 years) and 90 years (stand age 120 years).
7. Thinnings from below were made every 20 and 30 years to GSL's of 40, 60, 80, 100, 120, 140, and 160. Initial and subsequent entries were made to the same GSL.
8. A two-cut shelterwood option was used. The seed cut was made 20 years before final cut and retained 50% of the subsequent GSL.
9. Minimum size for inclusion in board-foot volume determination was 10 inches d.b.h. to a variable top diameter. Stand volumes were determined from tables prepared by Myers (1963).
10. All entries were made as scheduled, even though all thinnings could be precommercial.

[4]*Average stand diameter is the diameter of the tree of average basal area; it is not the average of all the tree diameters.*

Diameter Growth

Periodic mean annual diameter growth of southwestern ponderosa pine is related to stand density and site quality, but is affected little by the cutting cycles tested. Cutting cycles do influence average stand diameter, however, because thinning from below increases average diameter at each entry. Actual basal area in a stand with an average diameter of less than 10 inches d.b.h. continues to increase, because periodic thinning does not reduce basal area to a fixed (GSL) amount until an average stand diameter of 10 inches d.b.h. is reached. Consequently, the rate of diameter growth for a given GSL is not constant over time and is essentially a negative exponential function of basal area per acre in the program. In contrast, periodic diameter growth is a linear function of site index, so that differences in diameter growth resulting from site quality are constant throughout the range of GSL's and rotations examined.



igure 1.—Estimated average stand diameter of southwestern ponderosa pine in relation to age for different site classes at GSL 100, with a 20-year thinning interval and 120-year rotation.

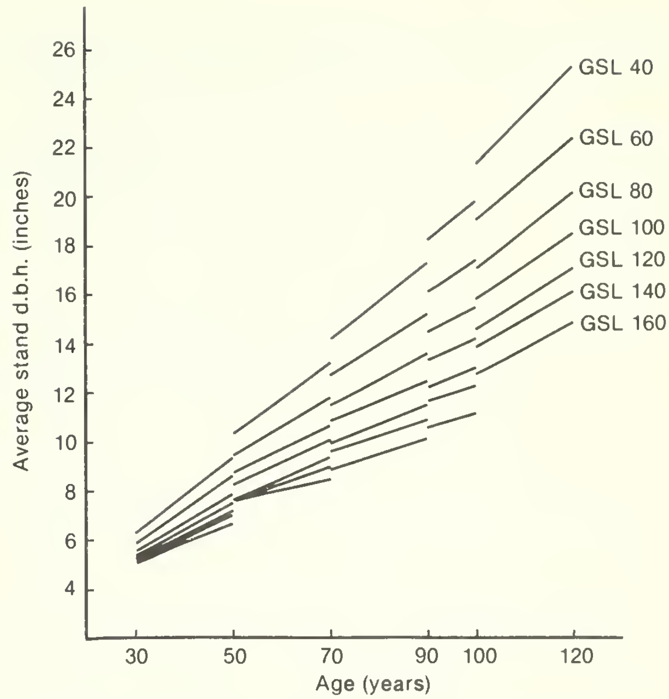


Figure 2.—Estimated average stand diameter of southwestern ponderosa pine in relation to age and GSL on site index 70 lands with a 20-year thinning interval and 120-year rotation.

Growth rates and changes in diameter resulting from thinning frequency were examined to determine average size of trees relative to rotation age. For example, at GSL 100 with a 20-year cutting cycle, trees reach average stand diameters of 12.3 to 14.4 inches d.b.h. after 80 years; and 16.4 to 20.7 inches d.b.h. after 120 years for the range of sites tested (fig. 1). On an average site (index 70), with a 20-year cutting cycle, mean stand diameters reached 10 inches d.b.h. at 50 to 88 years of age for the range of GSL's 40 to 160 (fig. 2).

Height Growth

Periodic mean annual height growth of ponderosa pine increases with site index and decreases with age, but is unaffected by GSL's or cutting cycles. However, because fewer and, therefore, taller trees are left after each thinning from below, the mean height of the dominant and codominant trees is increased slightly at each entry. The increase is positively correlated with thinning frequency and negatively correlated with GSL.

Basal Area Growth

Periodic mean annual basal area increment is related to growing stock level, site quality, frequency of thinning, and rotation age. Because actual basal area continues to increase in a stand until average stand diameter reaches 10 inches d.b.h. and thinning reduces basal area to a fixed amount (GSL), the rate of basal area growth for a given GSL is not constant over

Table 1.—Estimated total cubic foot volume production per acre of southwestern ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		thousand cubic feet						
		Site index 50						
80	20	2.13	2.43	2.68	2.88	3.00	3.06	3.13
120		3.04	3.67	4.08	4.39	4.60	4.74	4.82
80	30	2.20	2.53	2.72	2.87	3.00	3.10	3.13
120		3.14	3.76	4.21	4.45	4.60	4.67	4.69
		Site index 60						
80	20	2.53	2.93	3.27	3.54	3.74	3.86	3.94
120		3.66	4.44	5.02	5.44	5.82	6.00	6.08
80	30	2.62	3.03	3.36	3.57	3.73	3.89	3.99
120		3.76	4.58	5.23	5.64	5.94	6.12	6.30
		Site index 70						
80	20	3.00	3.52	3.91	4.19	4.49	4.70	4.80
120		4.30	5.28	6.05	6.66	7.20	7.56	7.68
80	30	3.14	3.61	3.99	4.30	4.56	4.76	4.84
120		4.52	5.45	6.28	6.86	7.37	7.73	7.97
		Site index 80						
80	20	3.44	4.13	4.63	4.98	5.26	5.46	5.63
120		4.94	6.18	7.18	7.97	8.62	9.00	9.24
80	30	3.70	4.21	4.67	5.11	5.41	5.56	5.67
120		5.32	6.50	7.44	8.18	8.76	9.16	9.28
		Site index 90						
80	20	3.95	4.69	5.35	5.87	6.24	6.46	6.56
120		5.63	7.08	8.35	9.35	10.15	10.51	10.75
80	30	4.24	4.95	5.59	6.06	6.33	6.48	6.52
120		6.10	7.49	8.69	9.55	10.08	10.56	10.99

time. Periodic basal area increment increases as GSL increases from 40 to 140, but the rate of increase diminishes as stand density increases. At GSL's above 140, basal area increment declines on all sites. Periodic mean basal area growth also increases as site index increases. Moreover, the differences in basal area growth between site classes become progressively greater as GSL increases. Periodic mean basal area increment is greater with a 30-year cutting cycle than with a 20-year entry at all rotation ages and GSL's examined.

Total Cubic-Foot Volume Increment

Cubic-foot volume production is related to stand density, site quality, rotation age, and frequency of thinning (table 1). Although mean annual cubic volume increment increases as GSL and site index increase, the rate of increase diminishes as GSL increases, while the differences in growth between site classes becomes greater (fig. 3) (table 2). Cubic volume increment will apparently continue to increase slightly at GSL's above

Table 2.—Estimated mean annual total cubic foot volume increment per acre of southwestern ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		cubic feet						
		Site index 50						
80	20	26.6	30.4	33.5	36.0	37.5	38.2	39.1
120		25.3	30.6	34.0	36.6	38.3	39.5	40.2
80	30	27.5	31.6	34.0	35.9	37.5	38.8	39.1
120		26.2	31.3	35.1	37.1	38.3	38.9	39.1
		Site index 60						
80	20	31.6	36.6	40.9	44.2	46.7	48.2	49.2
120		30.5	37.0	41.8	45.3	48.5	50.0	50.7
80	30	32.8	37.9	42.0	44.6	46.6	48.6	49.9
120		31.3	38.2	43.6	47.0	49.5	51.0	52.5
		Site index 70						
80	20	37.5	44.0	48.9	52.4	56.1	58.7	60.0
120		35.8	44.0	50.4	55.5	60.0	63.0	64.0
80	30	39.2	45.1	49.9	53.8	57.0	59.5	60.5
120		37.7	45.4	52.3	57.2	61.4	64.4	66.4
		Site index 80						
80	20	43.0	51.6	57.9	62.2	65.8	68.2	70.4
120		41.2	51.5	59.8	66.4	71.8	75.0	77.0
80	30	46.2	52.6	58.4	63.9	67.6	69.5	70.9
120		44.3	54.2	62.0	68.2	73.0	76.3	77.3
		Site index 90						
80	20	49.4	58.6	66.9	73.4	78.0	80.8	82.0
120		46.9	59.0	69.6	77.9	84.6	87.6	89.6
80	30	53.0	61.9	69.9	75.8	79.1	81.0	81.5
120		50.8	62.4	72.4	79.6	84.0	88.0	91.6

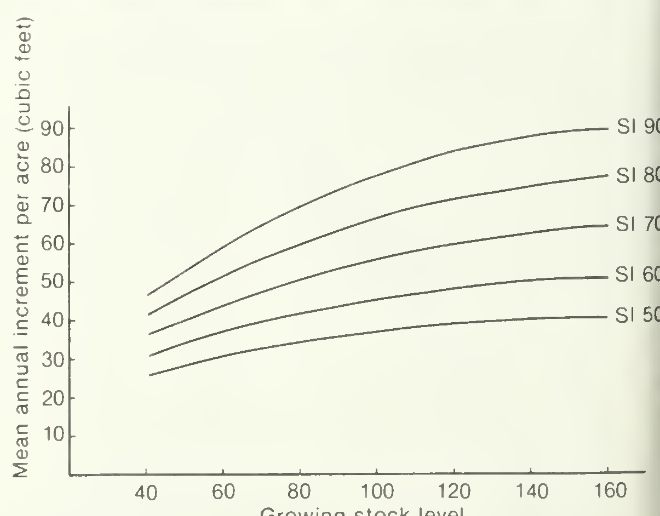


Figure 3.—Estimated mean annual total cubic-foot volume increment per acre of southwestern ponderosa pine in relation to GSL and site quality for a 120-year rotation with a 20-year thinning interval.

Table 3.—Estimated total board foot volume production per acre of southwestern ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index (trees 10 inches d.b.h. and larger to a variable top diameter)

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		thousand board feet						
		Site index 50						
80	20	3.36	3.68	4.00	4.40	4.40	4.16	3.68
120		8.40	9.84	10.80	11.28	11.28	10.56	9.60
80	30	3.28	3.60	3.84	4.08	3.92	3.60	3.04
120		8.40	9.84	10.56	10.92	10.80	9.96	8.64
		Site index 60						
80	20	4.48	5.04	5.44	5.76	6.00	6.00	5.76
120		10.92	12.72	14.16	15.24	15.60	15.36	15.00
80	30	4.40	4.80	5.20	5.44	5.68	5.52	5.20
120		10.68	12.72	13.80	14.52	14.76	14.64	14.40
		Site index 70						
80	20	5.60	6.24	6.72	7.20	7.60	8.00	8.16
120		13.08	15.72	17.64	18.96	20.04	20.64	21.00
80	30	5.44	6.16	6.64	7.04	7.28	7.28	7.20
120		13.56	15.96	17.88	19.08	19.92	20.16	20.40
		Site index 80						
80	20	6.80	7.68	8.48	9.04	9.44	9.92	10.24
120		15.96	18.96	21.48	23.40	25.20	26.64	27.36
80	30	7.04	7.76	8.40	8.96	9.20	9.36	9.44
120		17.04	19.68	22.08	24.24	25.44	26.04	26.40
		Site index 90						
80	20	8.08	9.20	10.24	11.04	11.84	12.32	12.64
120		18.84	23.16	26.64	29.40	31.44	32.76	33.60
80	30	8.56	9.28	10.16	10.88	11.20	11.52	11.76
120		20.64	23.64	26.76	29.52	30.96	31.92	32.40

160 on sites 70 and greater, but levels off or declines on site indexes less than 70 at GSL's greater than 160. Cubic foot growth is generally unrelated to length of rotation or cutting cycle at all GSL's tested when site index is less than 70. On site index 70 and greater lands, cubic-volume growth is greater on 120-year rotation at GSL's greater than 60, but there are no practical differences between a 20- and 30-year cutting cycle (table 2).

Board-Foot Volume Increment

Board-foot volume production is related to all stand parameters evaluated (table 3). Mean annual sawtimber volume growth increases as stand density increases throughout the range of GSL's on site index 80 and 90 lands, but generally levels off on site index 70 lands at GSL 140, and declines on site index 50 and 60 lands at GSL's 100 and 120, respectively (fig. 4) (table 4).

Board-foot volume growth increases with site quality, and the differences in growth between site classes

Table 4.—Estimated mean annual board-foot volume increment per acre of southwestern ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index (trees 10 inches d.b.h. and larger to a variable top diameter)

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		board feet						
		Site index 50						
80	20	42	46	50	55	55	52	46
120		70	82	90	94	94	88	80
80	30	41	45	48	51	49	45	38
120		70	82	88	91	90	83	72
		Site index 60						
80	20	56	63	68	72	75	75	72
120		91	106	118	127	130	128	125
80	30	55	60	65	68	71	69	65
120		89	106	115	121	123	122	120
		Site index 70						
80	20	70	78	84	90	95	100	102
120		109	131	147	158	167	172	175
80	30	68	77	83	88	91	91	90
120		113	133	149	159	166	168	170
		Site index 80						
80	20	85	96	106	113	118	124	128
120		133	158	179	195	210	222	228
80	30	88	97	105	112	115	117	118
120		142	164	184	202	212	217	220
		Site index 90						
80	20	101	115	128	138	148	154	158
120		157	193	222	245	262	273	280
80	30	107	116	127	136	140	144	147
120		172	197	223	246	258	266	270

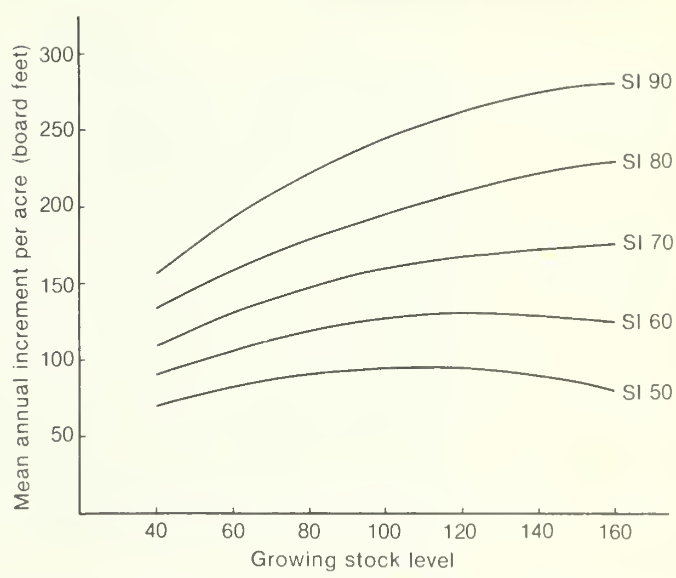


Figure 4.—Estimated mean annual board foot volume increment per acre of southwestern ponderosa pine in relation to GSL and site quality for a 120-year rotation with a 20-year thinning interval.

becomes greater as GSL increases. Throughout the range of GSL's tested, average annual board-foot increment per acre is always greater for all site classes on a 120-year rotation than on 80-year rotation (fig. 5). There are no practical differences in board-foot volume growth between 20- and 30-year cutting cycles for the range of site indexes and GSL's tested (table 4).

Maximizing Board-Foot Volume Yields

What yields can be expected with intensive management of southwestern ponderosa pine to maximize timber production? If the objective is to integrate timber production with other resources uses, what are the timber tradeoffs? How can these objectives be attained with the fewest precommercial thinnings?

The largest volume production per acre (33,600 fbm) is attained on site index 90 lands, at GSL 160, on a 120-year rotation, with a 20-year cutting cycle (table 3). These stands will contain about 72 trees per acre with an average d.b.h. of nearly 17 inches at rotation age (table 5).

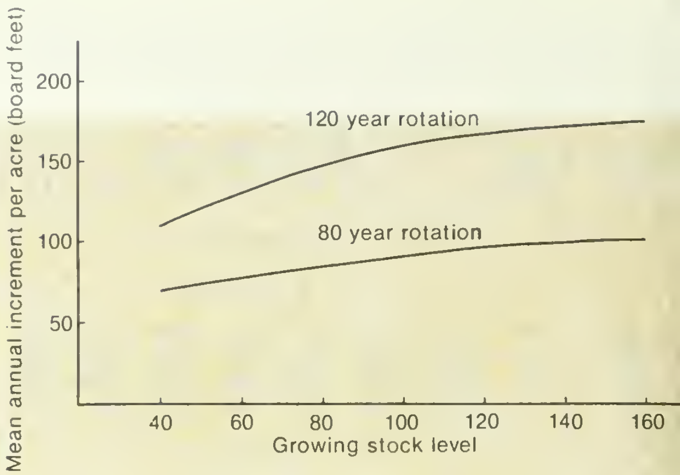


Figure 5.—Estimated mean annual board-foot volume increment per acre of southwestern ponderosa pine on site index 70 lands with a 20-year thinning interval in relation to GSL and rotation age.

Table 5.—Estimated average diameter (inches) and number of trees per acre of southwestern ponderosa pine at final harvest in relation to growing stock level, rotation age, cutting cycle, and site index

		Growing stock level													
		40		60		80		100		120		140		160	
Rotation age	Cutting cycle	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter
								Site index 50							
80	20	22	16.5	39	14.8	64	13.3	92	12.3	119	11.5	153	10.8	189	10.2
120		9	23.7	18	20.6	29	18.5	46	16.4	63	15.3	89	13.9	123	12.6
80	30	24	15.9	45	14.1	72	12.7	101	11.7	131	11.0	165	10.4	202	9.8
120		10	22.9	20	19.6	33	17.6	50	15.9	67	14.9	94	13.6	128	12.4
								Site index 60							
80	20	21	17.0	38	15.3	60	13.9	83	13.0	111	12.1	145	11.3	180	10.7
120		9	24.4	17	21.5	27	19.4	40	17.6	56	16.3	77	15.0	105	13.7
80	30	23	16.4	42	14.6	67	13.2	92	12.4	124	11.5	155	10.9	192	10.3
120		10	23.5	18	20.7	30	18.5	45	16.7	62	15.6	82	14.6	109	13.5
								Site index 70							
80	20	20	17.5	36	15.8	55	14.5	80	13.3	106	12.6	132	12.0	168	11.2
120		8	25.4	15	22.5	25	20.2	37	18.5	52	17.1	66	16.2	90	14.9
80	30	21	17.1	39	15.2	63	13.8	90	12.7	120	11.9	147	11.4	183	10.7
120		9	24.8	17	21.7	28	19.2	41	17.6	56	16.5	74	15.5	99	14.3
								Site index 80							
80	20	18	18.3	34	16.4	53	15.0	77	13.7	100	13.1	130	12.3	154	11.9
120		7	26.9	14	23.5	22	21.4	34	19.4	46	18.2	62	16.9	79	15.9
80	30	20	17.7	37	15.8	61	14.1	85	13.2	110	12.6	142	11.8	174	11.2
120		8	25.8	15	22.7	25	20.4	38	18.5	50	17.5	68	16.2	87	15.3
								Site index 90							
80	20	17	18.9	32	16.9	50	15.5	71	14.4	94	13.6	119	13.0	148	12.3
120		7	27.6	13	24.4	21	22.2	30	20.7	41	19.2	55	18.0	72	16.8
80	30	20	17.9	36	16.2	55	14.9	79	13.8	106	13.0	132	12.4	165	11.7
120		8	26.6	14	23.7	22	21.6	34	19.5	46	18.3	60	17.3	78	16.2

Volume production substantially declines when GSL is reduced below 160 on site index 70, 80, and 90 lands. The decline is greater with each successive reduction in stand density. Maximum volume production is at GSL's 100 and 120, on site index 50 and 60 lands, respectively, with a 20-year cutting cycle (table 3) (fig. 6).

Table 3 also shows the amount volume given up as GSL is reduced from the level of maximum production to GSL 40 for all combinations of stand parameters examined. Moreover, it shows that more volume can be produced over the same time span with 120-year rotations than with 80-year rotations. For example, on site index 90 lands, maximum board-foot volume production per acre from two 120-year rotations, or 240 years, would be 67,200 fbm, compared with 37,900 fbm on three 80-year rotations, also 240 years.

Whether the board-foot volume production potentials can be achieved depends largely on how much money can be invested in thinning. It is assumed that once a stand reaches a minimum merchantable size of 10 inches average d.b.h., market conditions permit intermediate thinnings to be made as scheduled. If economic constraints limit managers to only one precommercial thinning in the life of the stand, their options are severely restricted. For example, on site index 50 to 60 lands, stand density must be reduced to GSL 40 and the cutting cycle increased to 30 years (table 6). On site index 70 and 80 lands, a GSL of 60 can be maintained with a 30-year cutting cycle, and on site index 90 lands, a GSL of 100 can be maintained.

Table 6.—Number of precommercial thinnings of southwestern ponderosa pine in relation to growing stock level, cutting cycle, and site index

Cutting cycle	Site index	Growing stock level						
		40	60	80	100	120	140	160
years								
20	50	2	2	3	3	4	4	4
	60	2	2	2	3	3	4	4
	70	2	2	2	3	3	3	4
	80	2	2	2	2	3	3	4
	90	1	1	2	2	2	3	3
30	50	1	2	2	2	3	3	3
	60	1	2	2	2	2	3	3
	70	1	1	2	2	2	2	3
	80	1	1	2	2	2	2	2
	90	1	1	1	1	2	2	2

Thinnings to a constant GSL have been assumed up to now. However, if only one precommercial thinning is possible, managers can increase their flexibility by changing GSL's with successive reentries. For example, on site index 70 and 80 lands with a 30-year cutting cycle, stand density is initially reduced to GSL 60. At the time of the second thinning, GSL is increased to 80, and increased to GSL 100 with the third thinning. Volume production will be less than maximum, but reasonably close to the volume available from a stand maintained at a constant GSL 100. Attempts to raise the GSL to 100 at the time of the second entry into the

Figure 6.—Second growth southwestern ponderosa pine on site index 60 lands (Meyer 1961) thinned to GSL 120, Taylor Woods near Flagstaff, Ariz. Stand was about 45 years old when thinned in 1962.

stand would result in a second precommercial thinning. By following this procedure, managers can increase GSL on site index 50 and 60 lands from 40 to 80.

The manager has another option if only one precommercial thinning is possible. The initial thinning can be made on schedule and the second entry delayed until the stand reaches minimum merchantable size. This will increase the second thinning interval to 40 years or more, increase the length of the rotation, and result in less than maximum volume production.

Where economic conditions permit investment of funds in two precommercial thinnings, the manager has the opportunity to maximize timber production on site index 50 to 90 lands, with 30-year thinning schedule.

Tradeoffs to Increase Values of Other Resources

Understory vegetation in southwestern ponderosa pine is an important forage source for livestock and big game animals, but as overstory density increases, the productivity of the understory decreases. This inverse relationship is generally shown to be curvilinear (Pearson 1964, Jameson 1969, Clary 1969). Generally, herbage yields on productive sites can vary from 50 to 75 pounds per acre under dense timber stands (basal area per acre of 140 square feet) to 1,000 to 1,200 pounds per acre on moderately grazed open grasslands (Clary 1975) (fig. 7). High herbage production on these sites can be expected in clearcut openings until new tree regeneration becomes limiting. Actual changes in herbage production will vary considerably, however, depending upon habitat type, successional stage, and past grazing history, as well as overstory density.

In partially cut or thinned stands, herbage production generally is substantially greater than under uncut stands only when stand density is reduced to 70 square feet or less of basal area per acre, and differences in herbage production become progressively greater as

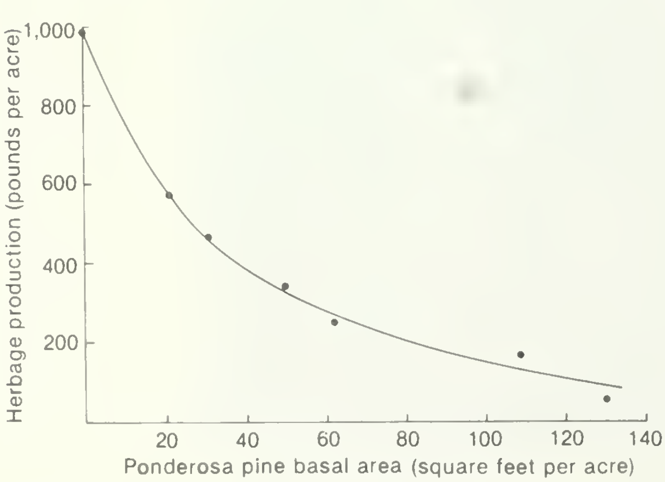


Figure 7.—Relation of herbage production to basal area of southwestern ponderosa pine on the Wild Bill range north of Flagstaff, Ariz. (Clary 1975).

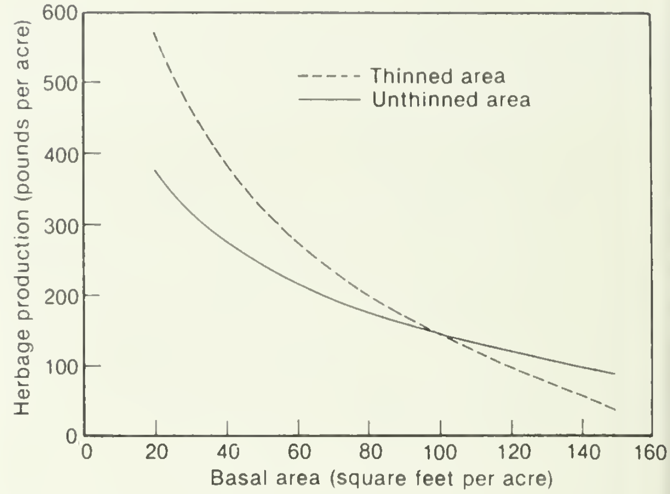


Figure 8.—Relationship between herbage production and basal area of southwest ponderosa pine on thinned and thinned areas, Beaver Creek Watershed near Flagstaff, Ariz. (Clary and Ffolliott 1966).

stand density in the thinned stands is reduced to 20 square feet of basal area per acre (Clary and Ffolliott 1966, Pearson 1967) (fig. 8). Moreover, herbage production under partially cut or thinned stands usually peaks about 5 years after treatment and will exceed production in uncut stands for only 10 to 15 years (Reynolds 1962).

Although no methods or data are available to quantify changes in understory herbage production under southwestern ponderosa pine for the range of GSL's, site indexes, rotation ages, and cutting cycles examined here, some general conclusions can be drawn. To increase average herbage production to even moderate levels (350 to 400 pounds per acre), the manager must be willing to reduce basal area stocking per acre to GSL 60 or less (fig. 9). To maintain forage production, the manager must be able to make additional cuts in the stand at intervals of at least every 20 years.

Southwestern ponderosa pine forests yield less water than subalpine and mixed conifer forests (Rich and Thompson 1974, Leaf 1975). The proportion of water available for streamflow (3 to 5 inches) to precipitation (20 to 25 inches) is low because of high evapotranspiration demand from vegetation during a long, warm growing season, and the variability of precipitation (Hibbert 1979). Water yield is derived mostly from snowmelt, and snowfall regimes are highly variable in the Southwest. Streamflow is greatest when winter snowfall is sufficient to maintain a continuous snowpack and soil moisture is recharged during the spring melt. Major runoff also occurs when rain falls on snow. Regimes that produce intermittent snowpack—snowfall followed by dry periods that melt the snow, or years of light snowfall—contribute little to streamflow. Weather from snowmelt to July is usually dry, and late summer rains only partially replenish losses from evapotranspiration.

The potential for increasing streamflow in ponderosa pine forests is also low. The largest increases (1 t

2 inches) occur when timber is harvested by clearcutting (Brown et al. 1974). The most effective pattern of timber harvest for increased water yields in ponderosa pine forests when precipitation is largely snow and redistribution by wind is significant is to clearcut about 30% to 40% of a drainage in small, irregular-shaped patches about five times tree height across, interspersed with uncut patches of about five to eight tree heights across (Gary 1975). If snowfall is not significant or redistribution of snow by wind is not a factor, larger clearcut openings are more effective in increasing streamflow. In this case, the increase in streamflow is largely a result of the reduction in consumptive use by vegetation. With harvest cutting methods that leave a residual stand or thinning, the increase in water yield will be less than with clearcutting and generally in an inverse proportion to the amount of basal area left.

Based on information available from research, observations, and experience, it is clear that stand density must be reduced to and maintained at low stocking levels (GSL's of 60 or less) to benefit forage and water resources. For example, on site index 80 lands, at GSL 80, with a 120-year rotation, and a 20-year thinning schedule, 5,880 fewer fbm per acre will be produced than at GSL 160. If the GSL is reduced to 40, the loss in volume production per acre is 11,400 fbm. Foreground landscape esthetics and developed and dispersed recreation opportunities are generally improved at moderate (GSL 80 to 100) stocking levels. Considerable timber volume is given up, however, at both low to moderate stocking levels.

Middleground and background landscapes require combinations of cleared openings, high and low stocking levels, and uncut timber to provide the variety and contrast that is visually pleasing. Some wildlife species require openings, others open-standing timber, while the habitat still of others is devastated by any kind of timber cutting. But until the habitat requirements of specific wildlife species are better known, the benefits and losses to wildlife cannot be determined for stand parameters examined here.

Management Caution

This simulation program estimates growth responses to different stand parameters that appear reasonable and consistent within the limits of current knowledge, but no southwestern ponderosa pine stand has been under management for a long time, and simulation extends beyond the limits of the available data base. Comparisons of estimates with actual values from plots established to provide growth information will be needed to verify simulated responses.

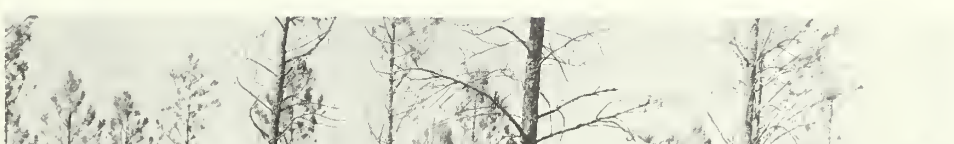


Figure 9.—Second-growth southwestern ponderosa pine on site index 60 lands (Meyer 1961) thinned to GSL 30, Taylor Woods near Flagstaff, Ariz. Stand was about 45 years old when thinned in 1962.

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Appendix

Table A-1.—Basal areas (square feet per acre) after intermediate cutting in relation to average stand diameter (inches) and growing stock level

Average stand d.b.h. after cutting	Growing stock level										
	40	50	60	70	80	90	100	110	120	140	160
2	6.0	7.5	9.1	10.6	12.1	13.6	15.1	16.7	18.2	21.2	24.2
3	11.8	14.8	17.7	20.6	23.6	26.6	29.5	32.4	35.4	41.5	47.4
4	17.6	22.0	26.4	30.8	35.2	39.6	44.0	48.4	52.8	61.6	70.4
5	23.4	29.2	35.0	40.9	46.7	52.5	58.4	64.2	70.0	81.9	93.6
6	28.3	35.4	42.4	49.5	56.6	63.7	70.8	77.8	84.9	99.0	113.2
7	32.7	40.9	49.1	57.3	65.5	73.7	81.9	90.1	98.2	114.4	130.8
8	36.2	45.3	54.4	63.4	72.5	81.6	90.6	99.7	108.8	126.9	145.0
9	38.8	48.4	58.1	67.8	77.5	87.2	96.9	106.6	116.2	135.6	155.0
10 +	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	140.0	160.0

Table A-2.—Number of trees per acre in relation to average stand diameter (inches) and growing stock level

Average stand d.b.h. after thinning	Growing stock levels										
	40	50	60	70	80	90	100	110	120	140	160
2	277	345	418	488	553	626	692	767	836	968	1,107
3	241	301	360	420	481	542	601	660	721	843	964
4	202	252	302	353	403	454	504	554	605	707	808
5	172	214	257	300	342	384	428	471	513	601	687
6	144	180	216	252	288	324	361	396	432	505	577
7	122	153	184	214	245	276	306	337	367	428	489
8	104	130	156	182	208	234	260	286	312	364	415
9	88	110	132	154	175	197	219	241	263	307	351
10	73	92	110	128	147	165	183	202	220	257	293

Table A-3.—Average distance (feet) between residual trees in relation to average stand diameter (inches) and growing stock level

Average stand d.b.h. after thinning	Growing stock level										
	40	50	60	70	80	90	100	110	120	140	160
2	12.5	11.1	10.2	9.4	8.8	8.3	7.8	7.5	7.2	6.7	6.3
3	13.4	12.0	11.0	10.2	9.5	9.0	8.5	8.1	7.8	7.2	6.7
4	14.7	13.2	12.0	11.1	10.4	9.8	9.3	8.9	8.5	7.9	7.3
5	15.9	14.4	13.0	12.0	11.3	10.6	10.1	9.6	9.2	8.5	8.0
6	17.4	15.6	14.4	13.2	12.3	11.6	11.0	10.5	10.0	9.3	8.7
7	18.9	16.9	15.4	14.3	13.3	12.6	11.9	11.4	10.9	10.1	9.4
8	20.5	18.3	16.7	15.5	14.5	13.6	13.0	12.3	11.8	10.9	10.2
9	22.3	20.1	18.2	16.8	15.8	14.9	14.1	13.4	12.9	11.9	11.1
10	24.4	21.8	20.1	18.4	17.2	16.2	15.4	14.7	14.1	13.0	12.2

Alexander, Robert R., and Carleton B. Edminster. 1980. Management of ponderosa pine in even-aged stands in the Southwest. USDA Forest Service Research Paper RM-225, 11 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

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Keywords: Stand growth, stand yield, forest management, *Pinus ponderosa*

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Sterilization of Dominant Males Will Not Limit Feral Horse Populations

Kurt J. Nelson

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Sterilization of Dominant Males Will Not Limit Feral Horse Populations

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Abstract

Sterilization of dominant stallions is impractical for controlling feral horse populations. Evidence does not support the premise that reproductive units are stable, with one male and many females. Individual horses, including reproductively active females, move between bands during the breeding season.

[1]The author was a graduate student, New Mexico State University, Las Cruces. This research was supported by the Rocky Mountain Forest and Range Experiment Station with headquarters at Fort Collins in cooperation with Colorado State University and by the New Mexico State University Agricultural Experiment Station in Las Cruces. The manuscript was submitted as New Mexico State University Agricultural Experiment Station Journal Article 774. Supervision was provided by David R. Patton, project leader at the Station's research work unit at Tempe in cooperation with Arizona State University.

Sterilization of Dominant Males Will Not Limit Feral Horse Populations

Kurt J. Nelson

Management Implications

Permanent or temporary sterilization of the dominant stallion in a feral horse herd has been suggested to control horse populations. This control method would work only if bands of horses were stable, if reproductive units consisted of one male and many females, and if females did not move between bands. A study of the behavior of bands of horses from the Jicarilla herd shows that female fidelity is weak or nonexistent and that some breeding in the bands is by subdominant males. The amount of sterilization that would have to be done to control horse numbers indicates that the technique is not practical. Another reason to avoid selective sterilization of dominant males is that these animals represent the best genetic material for the population.

Introduction

The Wild Free-Roaming Horses and Burros Act L 92-195) of 1971 provides federal protection and stody for feral equids, including feral horses (*Equus ballus*), on specified public lands. Prior to 1971, feral rse populations were limited through relatively unreicted removal of animals. Since protection began in 71, some of these populations may have increased at tes approaching 20-25% per year (Blaisdell 1977), sulting in overuse of available resources (Hall 1972). acceptable method is needed to regulate feral horse mbers at levels compatible with environmental conaints while maintaining the populations at viable els.

Population management has three distinct goals: (1) keep a species on a "sustained yield basis" (harvest me management); (2) to increase the density of a ecies that is dangerously low (endangered species nagement); or (3) to decrease the density of a species st management) (Caughley 1976). With respect to al horse populations on western rangelands, populan management might be viewed as an amalgamation goal 2, maintaining viable populations of feral ses, and goal 3, limiting growth of local populations t reach pest proportions.

ne suggested technique for imposing population conr artificially is temporary or permanent sterilization he dominant stallions in a feral horse population educe the rate of reproduction (Baxter 1977, Frei 97). The technique is appealing because it requires ipulation of only a few animals, and it is accept to various agencies and preservation groups (Naal Wild Horse Forum 1977).

he hypothesis that sterilization of dominant stalios would control population is based on the following smptions:

1. Only certain males (harem stallions) participate in the breeding.
2. The number of breeding males is small relative to the number of reproductively active females, so that one male breeds many females.
3. A feral horse society is composed of groups that are stable over time.
4. Any changes in band affiliations are primarily among the immature, prereproductive individuals in the population.

If any of these seemingly plausible assumptions is untrue, sterilization is not practical as an artificial means of imposing density limitations.

This hypothesis thus raises questions on feral horse biology: What is the sex and age composition of the population? When do mating and parturition occur? At what age do both males and females reach sexual maturity? What type of social organization is expressed? Are the dominant stallions of feral horse bands doing all of the breeding within their bands? Do peripheral males participate in breeding receptive females? How stable are feral horse bands, and how much exchanging of members between bands occurs? How are bands formed and who forms them?

Only recently have there been attempts to obtain information on the population biology of feral horses (Feist 1971, Feist and McCullough 1976, Green and Green 1977, Hall 1972, Hall and Kirkpatrick[2]).

Various authors have described the social organization of both wild and feral equids. Generally, they have noted two distinct types: those equids in which the males are strictly territorial, such as in Grevys zebra (*Equus grevyii*) (Klingel 1969a, 1975a, 1975b), in some

[2] *Hall, R., and J. F. Kirkpatrick. 1975. Biology of the Pryor Mountain Wild Horse. Unpublished report, 21 p. Bureau of Land Management, Salt Lake City, Utah.*

feral ass (*E. asinus*) populations in Death Valley (Moehlman 1974), and those equids in which the males are nonterritorial and form harem units, such as in plains zebra (*E. quagga*), mountain zebra (*E. zebra*) (Klingel 1966, 1967, 1968, 1969b, 1975b), and feral horse (*E. caballus*) (Fiest 1971, Feist and McCullough 1976, Green and Green 1977).

Feist (1971), Feist and McCullough (1976), and Green and Green (1977) stressed the highly stable nature of the harem social unit in their studies of feral horse populations. Band stability, it is hypothesized, is determined by the stallion's dominance over the other individuals of his band. Interchanges that did occur were primarily in the prereproductive segment of the population. Thus, a feral horse society is thought to be one of female fidelity to a particular band and not one of sporadic association with many different bands.

It can be concluded from computer simulations of population responses to changes in demographic parameters that sterilization of the dominant stallions is an impractical method of population control (Nelson 1978). It was shown that to initiate a population decline, the percent of successful breeding of females must be reduced to less than 10% (fig. 1).

Another method of control of these populations appears to be continuous cropping of 15% of the population per year. Cropping of entire band units would cause the least disruption to the social structure of the entire population. For a discussion of such a cropping procedure, see Fowler and Smith (1973). For a more thorough discussion of the computer simulations see Nelson (1978).

Figure 1.—Changes in the finite rate of increase in a feral horse population as a result of varying percent breeding. Proportion breeding shown at end of each line.

The research presented here is an evaluation of male sterilization techniques based on observations of population biology.

Study Area

The study area was on the Jicarilla District of the Carson National Forest, 90 km northeast of Farmington, N. Mex. The northern portion of this public land has been designated as the Jircarilla Wild Horse Territory and is approximately 29,000 ha. This study was restricted to 14,200 ha. The study area is heterogeneous, including four major canyons (10,000 ha) administered by the USDA Forest Service (FS) and 4,200 ha of land administered by the Bureau of Land Management (BLM). There is movement of feral horses across the FS-BLM boundary line.

Topographic features include wide canyon bottoms, steep-sided rocky slopes, and broad mesas. Elevations range from 1,800 to 2,275 m. The area lies within the San Juan Basin, with underlying rock of the Wasatch and Naciminento formations. The mesa soils are of sandstone origin and quite variable. The slopes and bottomlands are a mixture of soils derived from shale and sandstone and are easily eroded (Dane 1948, Simpson 1950). There are alluvial deposits 6 m or more in depth in the main canyons; canyon bottoms vary in width from a few hundred meters to 1.5 km or more. Deep gullies have been cut through the alluvia, and sheet erosion is common.

Precipitation occurs in the form of winter snow and summer rains. Water availability is limited during the dry months prior to the onset of summer rains. The development of stock tanks to hold runoff and the presence of intermittent springs along the main canyons provide water sources during the drier months. With the onset of the summer rainy season, water is readily available throughout the area.

Vegetative types include sagebrush-grass association, pinyon-juniper woodland association, pinyon-juniper-sagebrush-grass ecotone association, pine/Douglas-fir association, and revegetation association.

Approximately 800 ha of range revegetation has been done in the study area over the past 10 years. These areas begin vegetative growth 3 to 5 weeks earlier than the surrounding nonmanipulated land. A corresponding increase in use of these areas by feral horses, mule deer (*Odocoileus hemionus*), and elk (*Cervus elaphus*) was noted in response to early spring growth. Revegetation areas provide an important food source before spring growth begins on other parts of the range. A substantial road network exists on the study area enabling fairly complete coverage from a vehicle.

Methods

This study involved intensive observation of daily nd seasonal activity of selected feral horse bands. 'he usual procedure was to observe a band for 4 to 12 ours. Most of the study area was visited at least every or 3 days.

A 20X spotting scope, 8X binoculars, and a tape ecorder were used. Observations were recorded in ıree formats, adapted from procedures outlined by ıltmann (1974). Behavior-time matrices, including both ocial and nonsocial behaviors, were constructed for bservations of bands and individuals within bands. 'he number of horses engaged in different activities /as recorded at 5-minute intervals, and the relative osition of the horses plotted. During each hour that a and was observed, activities of a randomly chosen inividual were observed for 30 minutes and recorded eparately. For individuals, observed activities were oted as occurring within any given minute during the 0-minute observation period (Lagerspetz 1964, Conley 976). Band identification, date, time, weather conitions, vegetative association, and location were reorded for all observations. In addition, sex, age, idenfying color and marks, and familial relationships (as iscernible) were recorded on the individual's data heets. A continuous account of all other behavior was ecorded throughout an observation period in conjunc-.on with the other two formats. From these three ıethods of recording information, construction of a omplete behavior profile is possible for both individal and group activity patterns over the course of a ear.

An aerial count of the feral horse population was onducted January 18-20, 1977, after sufficient snowıll to facilitate observation. This aerial survey and nowledge of the number of horses in the study area ere used to estimate total population size.

Fieldwork began on September 13, 1976, and termiıted August 17, 1977. Approximately 1,100 hours of ehavior observations on individual horse bands and 0 hours of behavior observations on individuals ithin bands were recorded during the field study.

Results

The aerial census revealed 226 individuals in this pulation. The population segment that received inıse study consisted of 116 individuals in 17 different nds. Each band included a mature stallion, one to six ıture females and their offspring, and an assortment o immature females not necessarily of familial relan. Two bands contained more than one stallion.

Table 1 shows the age structure and composition of s population segment. Four age classes could be ognized: (1) foal, individuals up to 1 year of age; (2 yearling, individuals from 1 to 2 years of age; (3) imture, individuals from 2 to 3 years of age, and (4) ture, individuals 3-1/2 years and older. Some overla exists in the immature and mature age classes because of difficulty in determining the age of certain females. If the three youngest age classes are grouped together, 52.6% of the population was born between 1975 and 1977.

Table 1.—Sex and age composition of the population segment that received intense study in summer 1977

	Foal	Yearling	Immature	Mature	Total	Percent
Male	12	7	10	17	46	39.7
Female	9	9	14	38	70	60.3
Total	21	16	24	55	116	100.0
Percent of total population	18.1	13.8	20.7	47.4	100.0	
Ratio of males to females	1.33	0.77	0.71	0.44	0.66	

Very little is known of reproduction in feral horses. Nishikawa et al. (1952), Hafez and Jainudeen (1974), and Nishikawa and Hafez (1974) gave a thorough summary of reproduction in domestic horses. A brief description of reproduction in domestic horses provides a reference to evaluate feral horse reproduction. In domestic stallions, sexual maturity may be attained before the age of 2 years. Testicular growth begins at 11 months with spermatogenesis occurring by 12 months. Males possess viable sperm year-round, although photoperiod appears to affect both the quantity and quality of semen. A domestic stallion can normally service 60 to 80 females during the breeding season. In female domestic horses, sexual maturity may be attained as early as 12 to 18 months. Estrous may be acyclic at first, then becomes cyclic. The length of the estrous cycle varies from 16 to 24 days, and duration of estrus itself is 3 to 11 days. Ovulation occurs 24 to 48 hours prior to the end of estrus. Diestrus lasts 14 to 19 days when ovulation occurs and 7 to 10 days when ovulation does not occur. The duration of gestation is 340 ± 30 days. A post-partum estrus may occur 5 to 15 days following birth. In domestic horses, reproductive efficiency is low, with a 60-65% conception rate and 50% foaling rate. Abortion frequency is 10% with mares 3 to 6 years old having the lowest abortion frequency. Prenatal mortality is common to lactating mares mated early in the season and to those which conceive during post-partum estrus.

Based on recent field observations of feral horse populations, it appears that reproduction in feral horses is similar to that in domestic horses. Feist (1971) and Feist and McCullough (1975) observed that 43.2% of mature females foaled in 1970. Two mares in the immature age class foaled, and two sets of twins also were noted. The breeding season of this population of feral horses was restricted to the spring and summer, with all foals born between April and June, and a peak in foaling in May. All mating occurred within the harem unit with all copulations by the dominant male stallion. The behavioral sequences of mating have been described by Feist and McCullough (1976).

In the Jicarilla feral horse population, mating was observed throughout the year. Most observed copulations coincided with the spring and summer foaling season. Of 19 observed copulations, 17 were by dominant harem stallions. These stallions copulated with female members of their own bands and other receptive females. Nine of the observed copulations were with females from another band.

Evidence does not support the premise of stable reproductive units. Fidelity to a particular band is weak or nonexistent in many females of this population.

Twenty-one foals were born to the 38 mares in the mature class giving a 0.55:1 ratio. There were no twins. This rate of recruitment indicates most females do not foal in successive years, a finding that is further supported by field observations that 29% of the mares had foals in each of the past 2 years. The peak foaling period in this population occurred from April through May. By the end of May, 66% of all foals had been born, although foaling continued through the end of August.

There were differences in reproductive effort between females with access to revegetation areas and females without such access. Females with access to these areas began foaling on April 6 and completed foaling in May. Other females began foaling on May 3 and continued through August. Of the mature females, 64% had access to revegetation areas. These females contributed 73% of the foals (table 2).

Mortality was low in this feral horse population. During the study, 25 skulls were collected and age-at-death estimates were derived using tooth-eruption and tooth-wear criteria following procedures used by Ensminger (1969). Twenty-two of these horses were less than 12 years of age at the time of death. The presence of canine teeth indicated 15 of the skulls were from male horses (Ensminger 1969). There was no mortality in the foal class. Of 21 foals born in the spring and summer of 1977, all survived through August 1977 when this study ended. It is possible some mares gave birth to foals that died prior to being observed.

Table 2.—Differences in reproductive effort of females with access to revegetated areas and females without access

Activity area	Females	Foals	Foal to mare ratio	Standard error
	percent			
Revegetated areas	64	72	0.62	± 0.08
Nonrevegetated areas	36	28	.43	± .10
Total	100	100	.55	± .06

Different mortality rates between sexes are evident in this population. The male to female ratio at birth approaches 1.0; however, the sex ratio approaches 0.4 in the mature age classes. This suggests that males are incurring higher mortality or that a disproportionate number of males left the study area. Of 10 males in the immature age class, only 4 were in harem units, while all 14 females in this immature class associated with one or more harem bands.

Mountain lion (*Felis concolor*) and coyote (*Canis latrans*), both present in the study area, are potential predators on feral horse populations (Dobie 1952, Young and Goldman 1946). However, no deaths within this population could be attributed to predation during the study.

Observations suggest that survival patterns are characterized by low mortality in the foal and yearling classes, and higher male mortality in the immature and mature age classes. Dispersal movements are included as a component of mortality estimates, thus making estimates conservative.

Social Structure

A band is a recognizable aggregate of individuals in a somewhat stable association. A band may be a harem group or it may be an all-male aggregation of immature, subdominant members of the population. Female aggregations were not classified as bands because they were in frequent association with one or more harem groups over the course of the year. An assumption in this study was that the stallion is the alpha individual, thus band identity was determined by his presence or absence. Most bands contain a core of individuals which usually remain together with the stallion. I have called such a group the primary band. If a female was recognized as a member of a particular band but was not with the stallion, she was classified as out of the band.

The dynamics of group formation and group structure are of particular importance in a social system. Feral horse bands were formed in four ways: (1) peripheral males acquiring females from existing bands (observed three times); (2) peripheral males forming a band with females which had previously been moving between bands (observed twice, although neither was permanent); (3) a peripheral stallion assuming control over a harem band following disappearance of the dominant stallion (observed once); and (4) bands splitting into two new bands as a result of competition between two mature males (observed once and appeared to be happening in another band at the close of field observations).

Size and composition of some bands were fairly stable while others were unstable. Changes in band size and composition occurred throughout the year, but there was a strong seasonal pattern in some bands. The monthly mean size of each band indicated an increase in general movements of individuals between bands and out of bands during the spring and summer months. Certain bands having access to revegetation areas exhibited greater interchange of members beween bands (fig. 2). Prior to the onset of breeding and arturition in late March, these bands begin to break p, with females and their offspring moving between djacent bands. By May, very few females were with ieir primary band, and were either with another and, by themselves, or with all-female factions of a revious band. Bands not having access to revegetation reas appeared to be relatively stable (fig. 3). Conderable movement occurred even among the more able bands but was usually short-term, with individals returning to their primary band (fig. 4).

Sixty-one percent of the females in the study area ere either alone, or with other females and no stalon, or in association with another band at some time uring the year. Females moved more during the time f breeding and parturition. This amount of movement ould not necessarily negate the hypothesis that the opulation could be controlled by sterilizing dominant ales, provided the animals involved in the movement ere the nonreproductive and/or immature segments f the population. However, the most active segment of emales were mature (78% of the observed movements). nmature females had a higher movement activity in ie fall and winter periods. Yearling females generally ayed with their primary band, moving only with other emales.

Discussion

These findings suggest that dominant males do most f the breeding and that there are few such males elative to the number of sexually active females. owever, the majority of the observations were of ands which included a dominant stallion, resulting in bias in favor of such observations. While copulations volving peripheral stallions were not observed, the ct that females associate with these males at various mes, and spend long periods of time outside any rem band, suggests that some reproduction may be tributable to these males.

An explanation for the disproportionate sex ratio in e mature age class is not readily available. Two litary stallions and one group of five immature and bdominant stallions were observed during the study. spersal of males to areas outside the study area or ferential mortality directed toward the male segnt of the population are two possible reasons for the served imbalance; however, it seems possible that les from other areas would immigrate into this pulation segment, resulting in no net changes.

Most movements of individuals between bands or out bands coincided with the breeding season. Not only s there movement between groups, but this movent included the reproductively active females. The h percentage of the female population involved in er long- or short-term movements outside the mary band negates the effectiveness of male-limited pulation control. Evidence that over 50% of the erved copulations were with females from other ds further indicates the ineffectiveness of steriliz-only certain harem stallions.

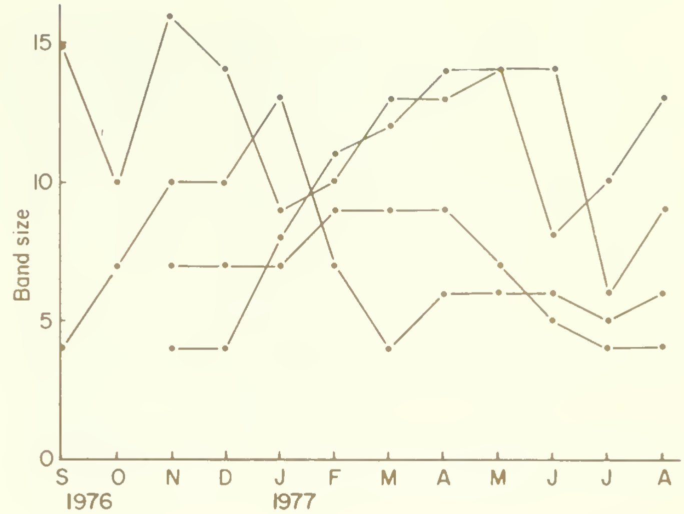

Figure 2.—Maximum monthly band size of four bands with access to revegetated areas.

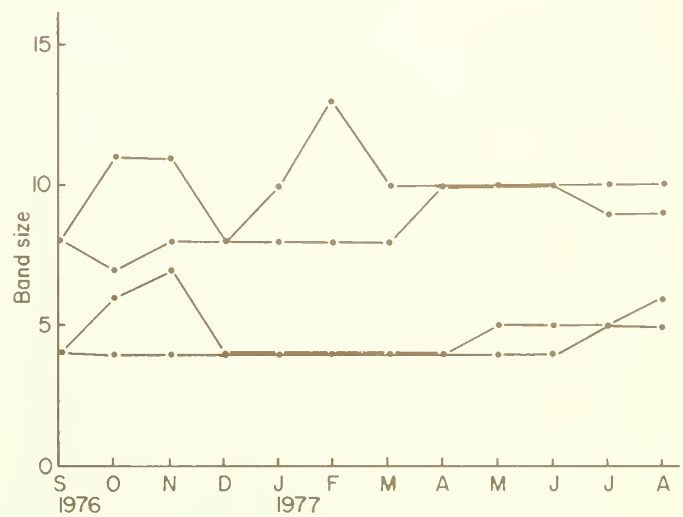

Figure 3.—Maximum monthly band size of four bands without access to revegetated areas.

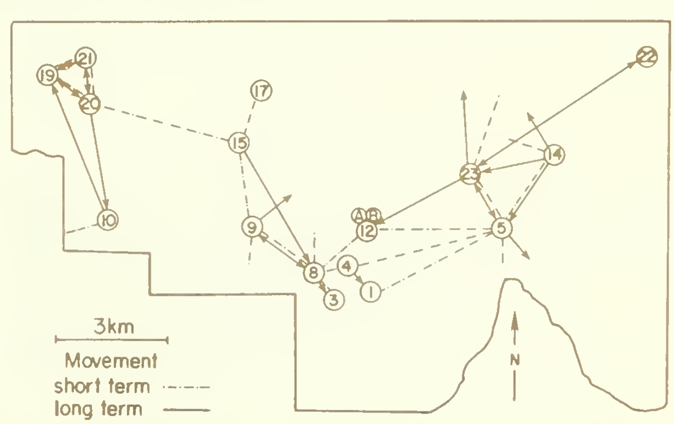

Figure 4.—Movement of individuals between bands and out of bands within the study area in the Jicarilla feral horse population.

Given the potential of feral horse populations to increase as evidenced in the past few years, it seems unlikely that sterilizing dominant males would reduce reproduction enough over the time necessary to cause a decline in numbers. Approximately 25% of the harem stallions were replaced each year. If these observations are representative of feral horse populations in general, male-sterilization techniques would have to be implemented on a yearly or every-other-year basis, an impractical management approach.

In addition to failing to limit the population, selective sterilization of alpha males would eliminate the major contributors of quality genetic material from the gene pool. Breeding by peripheral, subdominant males, might then introduce inferior genotypes, a result which runs counter to the management objective of maintaining viable feral horse populations.

Future Research

The biology of this population has been made more complex by the differential behavior of individuals with access to revegetation areas compared to those without access to such areas. The higher foal:mare ratio of females with access to revegetated areas implies increased reproductive value with increasing nutritional resources. Clegg and Ganong (1969) found that domestic mares would breed at any season if well fed. Hall (1972) relates reproductivity to nutrition in the Pryor Mountain feral horse population, since foaling coincided with the onset of spring growth of vegetation. That these females with access to revegetation areas are foaling earlier in the spring suggests that the timing of reproductive efforts are tied to differences in forage availability and are in this sense vegetation generated. While these differences do not directly relate to the questions of limiting population growth by sterilizing dominant males, a management alternative might be to concentrate on those groups of animals which exhibit higher production, if the goal is to limit growth of the population. Research completed by the University of Arizona will provide new information on the use of revegetated areas by wild horses.[3]

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Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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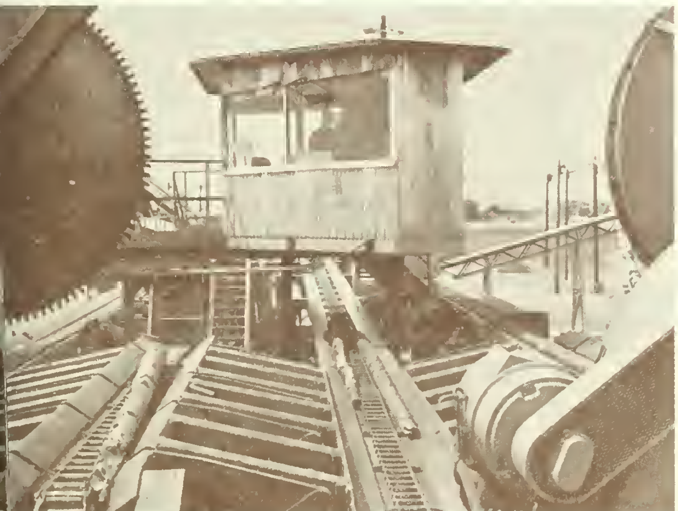
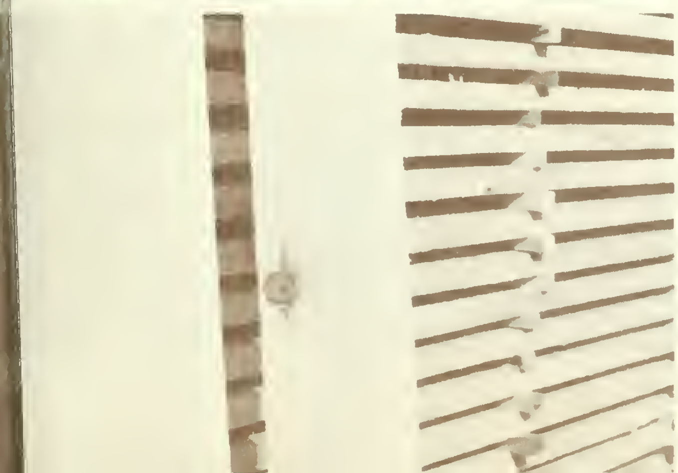

Lumber Yield Potential of Aspen in the Rocky Mountains

Eugene M. Wengert
and
Dennis M. Donnelly

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Lumber Yield Potential of Aspen in the Rocky Mountains[1]

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Abstract

The yield of sawn products from aspen (*Populus tremuloides* Michx.) trees from northern New Mexico and eastern Utah, both in terms of volume and dollar value, was related to trial tree and log grades. Trial grading systems generally allowed separation of trees and logs into different levels of volume and dollar value recovery.

[1]*This research was sponsored jointly by the Forest Products Laboratory, the Rocky Mountain Forest and Range Experiment Station, and the Intermountain Forest and Range Experiment Station. Special assistance was provided by R. O. Woodfin, Pacific Northwest Forest and Range Experiment Station; J. Hutt, Carson National Forest; D. Markstrom Rocky Mountain Station; and M. Koepke, Utah Forestry and Fire Control.*

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Lumber Yield Potential of Aspen in the Rocky Mountains

Eugene M. Wengert and Dennis M. Donnelly

Management Implications

This research attempted to relate lumber recovery to the characteristics of standing aspen timber. Although only limited inferences can be drawn from the results of this preliminary study, it provides valuable insights on the importance of various aspects of lumber volume and grade recovery in relation to visual characteristics of logs and standing trees. This also should be useful in revealing promising approaches to future, more thorough investigations of lumber yield from aspen.

Tree and log grades developed by Bailey (1973, 1974) have some potential for separating aspen trees and logs into value quality classes. Also, value classification based on tree diameter alone works fairly well. Further work will be necessary to confirm the applicability of these findings to aspen timber in other areas and under other utilization objectives. Caution should therefore be used in applying the data shown in tables 5 and 7 to other aspen stands. The data presented here are valid only for the distribution of log sizes sampled in this study, and then only with the reservations associated with small samples. Values can be expected to vary as the distribution of tree and log sizes changes within each grade.

Aspen (*Populus tremuloides* Michx.) is an underutilized species in the Rocky Mountain West. Although recent forest surveys show the Rocky Mountain states have more aspen sawtimber (more than 7 billion fbm of sawtimber) than any other area in the U.S., the annual harvest of this species in the West for sawn products is less than 10 million board feet. For optimum management of the species, annual harvests and utilization for sawn products could be approximately 60 million board feet.

Many factors contribute to this underutilization. One important reason may be widespread unfamiliarity with the possible uses of aspen and, therefore, an inability to assess the utilization potential of standing timber or logs.

One of the most obvious inadequacies is lack of information on the lumber recovery potential of aspen in the Rocky Mountains. To help provide this information, a very limited study at two mills was conducted under conditions that are typical of sawmills and logging operations cutting aspen in the Rocky Mountains.

Grading Systems

As part of the overall research effort on Rocky Mountain aspen, grading methods were evaluated that might prove useful in assessing the potential of standing aspen timber and saw logs for conversion into sawn wood products. One grading system selected for evaluation in this study was developed by Bailey (1973, 1974). This grading system is built around both tree diameter and quality. Because diameter is easier to measure in field situations, it was decided to test another simpler grading system based on tree diameter alone.

Two separate product classes were chosen for the evaluation: (1) 1-inch (2.5-cm) lumber graded with softwood grading rules, and (2) a combination of 2-inch (5-cm) dimension lumber and 4- by 6-inch (10- by 15-cm) mine timbers. Despite the fact that mine posts do not necessarily reflect grade quality, these product classes were selected because a previous review of the aspen problem in the Rocky Mountains indicated that market potential in the West for these products is higher than if aspen were used in more conventional hardwood products.[4]

Hardwood Tree and Log Grades

Tree and log grades developed and generally accepted for U.S. hardwoods are not appropriate for predicting lumber yields from aspen in the Rocky Mountains. Aspen lumber in the Rocky Mountains is now commonly graded, if at all, by softwood lumber rules and will likely continue to be, because it is sold and used mainly as a softwood. Another difficulty with using the standard hardwood grades is that aspen trees and logs in the Rocky Mountains fall almost entirely within the two lowest grades, which severely limits the value separation that can be obtained between the highest and lowest quality trees or logs. Because of the apparent incompatibility between the

[4] *In preparation for this study, Wengert contacted mill operators and others who utilized or marketed aspen products in the central and southern Rocky Mountains.*

purpose of the standard hardwood rules and the uses made of western aspen, other tree and log grading possibilities were explored.

Tree Grades

After studying various tree grades for assessing the potential of aspen in western Canada, Bailey (1974) developed some relatively simple grading rules that appeared to be effective. This study tested Bailey's grades for aspen in the Rocky Mountains.

Other relevant information about conk location and frequency came from two previous studies on aspen in Colorado (Hinds 1963, Hinds and Wengert 1977) that considered the influence of decay and *Phellinus tremulae* (= *Fomes igniarius*) on scaled tree volume. These latter studies indicated that aspen in the Rocky Mountains is most seriously affected by *P. tremulae* and, further, that the conks of this fungus are present and outwardly visible in 75% of the infections. To reflect the results of these studies, the tree grading rules developed by Bailey were modified to incorporate restrictions on the amount and location of conks (table 1).

The underlying philosophy of these tree grades is that d.b.h. is an indicator of both tree volume and of the probability of higher yields of upper grade boards usually obtained from larger trees. In contrast, conks and large scars indicate volume loss, especially in the lower sections of the merchantable bole where quality is normally expected to be higher, and quality loss from heavy staining.

Log Grades

Log grades used in this study for 8-foot (2.4-m) logs were Bailey's (1973), modified slightly by the authors (table 2).

Grades Based Only on Diameter

Because the mill phase of this study indicated that product volume and value were closely related to diameter, diameter was tested as a single parameter of value by regrading the trees and logs based only on the diameter limits of Bailey's rules (table 3).

Evaluation of Aspen Tree and Log Grades

Two methods of evaluating the effectiveness of log or tree grades were used in this study:

1. The ability to distinguish log or tree values (for example, dollar value per 100 cubic feet (2.83 m^3) or dollar value per unit of gross log scale).
2. The ability to distinguish the volume of lumber of particular grades (for example, the volume of No. 2 Common and Better in a diameter class).

Tree Selection

Trees were selected from two areas—the Carson National Forest near Taos, N. Mex., and the Uinta National Forest near Heber City, Utah. These were chosen, in part, because they represent two different market opportunities. Aspen from New Mexico is more accessible to eastern Rocky Mountain markets, including Albuquerque and Denver, for 1-inch (2.5-cm) lumber; aspen from Utah has a good potential for use in 2-inch (5-cm) lumber and posts for mines and other local markets. This difference in markets is reflected in the lumber sizes and grades manufactured (table 4).

The sampling plan was designed so that each modified tree grade category would be represented by the same number of trees. Trees were selected by starting

Table 1.—Trial tree grading criteria for aspen in the Rocky Mountains

Tree grade 1	Tree grade 2	Tree grade 3
d.b.h. 14 inches (36 cm) or greater with no conks and no scars more than 2 feet (61 cm) long in the lower 25 feet (7.6 m).	d.b.h. 10 to 13.9 inches (25 to 36 cm) with no conks and no scars more than 2 feet (61 cm) long in the lower 25 feet (7.6 m).	d.b.h. less than 10 (25 cm) inches with no conks and no scars more than 2 feet (61 cm) long in the lower 25 feet (7.6 m).
	---or---	---or---
	d.b.h. 14 inches (36 cm) or greater with limited conks,[1] or with scars more than 2 feet (61 cm) long, (scalable cull may run around 50%[2]).	d.b.h. (10 to 13.9 inches (25 to 36 cm) with limited conks,[1] or with scars more than 2 feet (61 cm) long, (scalable cull may run around 50%[2]).

[1]*Limited conks means either of the following conditions:*
a. Any number if all conks are below 16 feet (4.9 m) on the tree bole.
b. No more than three along the entire stem if any conks are above 16 feet (4.9 m) on the tree bole.
[2]*Not included in Bailey's tree grades.*

Table 2.—Trial tree grading criteria for aspen in the Rocky Mountains (8-foot logs)

Log grade 1	Log grade 2	Log grade 3
Straight logs, SED[1] 6 inches (15 cm) or greater, scalable decay less than 5%	Straight logs, SED 6 inches (15 cm) or greater, scalable decay 6% to 50%	Straight or sweepy logs, SED 5 inches (13 cm), scalable decay 0% to 50%
---or---	---or---	---or---
Sweepy logs,[2] SED 10 inches (25 cm) or greater, scalable decay less than 5%	Sweepy logs, SED 10 inches (25 cm) or greater, scalable decay 6% to 50%	Sweepy logs, SED 6 to 9 inches (15 to 24 cm), scalable decay 6% to 50%
	---or---	
	Sweepy logs, SED 6 to 9 inches (15 to 24 cm), scalable decay less than 5%	

[1]SED = small end diameter, inside bark.
[2]Sweepy logs have a deviation of 1.5 to 3.5 inches (3.8 to 8.9 cm) between the main axis and a line connecting the centers of end areas. Straight logs have a deviation of less than 1.5 inches (3.8 cm).

Table 3.—Trial grades for aspen trees and logs, based only on diameter

	Grade 1	Grade 2	Grade 3
Trees	d.b.h. 14 inches or over	d.b.h. 10 to 13.9 inches	d.b.h. less than 10 inches
Logs	SED[1] 10 inches or larger	SED 6 to 10 inches	SED less than 6 inches

[1]SED = small end diameter, inside bark.

Table 4.—Estimated 1975 prices for aspen lumber in the Rocky Mountains

Thickness and grade[1]	Dollars per thousand board feet
Manufactured in New Mexico	
1-inch, No. 2 Common or Better (boards)	212
1-inch, No. 3 Common (boards)	159
1-inch, No. 4 Common (boards)	132
1-inch, No. 5 Common (boards)	80
2-inch, Construction (light framing)	121
2-inch, Standard (light framing)	121
2-inch, Utility (light framing)	83
2-inch, Economy (light framing)	20
Manufactured in Utah	
1-inch, Construction (boards)	212
1-inch, Standard (boards)	159
1-inch, Utility (boards)	132
1-inch, Economy (boards)	80
2-inch, No. 1 (structural light framing)	121
2-inch, No. 2 (structural light framing)	121
2-inch, No. 3 (structural light framing)	83
2-inch, Economy (structural light framing)	20
Mine post, 4 by 6 inches	120

[1]All grades except 4- by 6-inch mine posts are published by the Western Wood Products Association in "Grading Rules for Western Lumber" (annual editions). Sections 30.10 and 40.10 apply to New Mexico, and Sections 30.50 and 42.10 apply to Utah. Prices are for lumber graded when green.

at one edge of the designated site and proceeding through the site to select the trees required to meet d.b.h. and grade requirements. Each tree was assigned a number.

After selecting and grading a tree, it was felled and bucked into haulable logs up to 33 feet (10 m) long in multiples of 8.25 feet (2.5 m). Lengths and diameters of logs were measured and recorded. Each log was numbered with respect to position in the tree and tree number.

Log Processing

After logs were hauled to the cooperating mill in New Mexico or Utah, they were bucked into 8.25-foot (2.5-m) lengths, renumbered, measured for diameter inside bark at both ends, scaled (Scribner), and graded using the modified Bailey log grade rules. Both mills sawed the logs with a circular-saw head rig. All lumber was tallied and, except for the mine posts at the Utah mill, graded green using Western Wood Products Association rules in effect in 1975. These rules permit grading of aspen as a softwood (Western Wood Products Association 1974). The New Mexico mill was sawing 1-inch (2.5-cm) lumber; however, the dog board[5] was always 2 inches (5 cm) and was not resawn.

At the Utah mill, 4-inch by 6-inch by 8-foot (10-cm by 15-cm by 2.5-m) mine posts were sawn from the smaller logs (less than 10 inches small end diameter) along with occassional pieces of 1- or 2-inch (2.5- or 5-cm) lumber. The larger logs were sawn only into 2-inch (5-cm) lumber with an occasional 1-inch (2.5-cm) board. This approach was used by the mill operator to improve recovery and profits, because mine posts can have heavy wane (which is likely when sawing small crooked logs), while 2-inch (5-cm) lumber grades are much less tolerant of wane. This practice results in high overruns for small logs.

Aspen Product Prices

To evaluate the grading systems, prices were estimated (table 4) at the time of the study on the basis of advice from USDA Forest Service personnel and mill operators in the two regions. All prices for aspen, except for the 4- by 6-inch (10- by 15-cm) posts, were lower than local conifer prices for the same product, reflecting a general lack of markets for aspen.

Evaluation Methods

Data for the study are separated and evaluated in four separate groups: Utah tree grades, New Mexico tree grades, Utah log grades, and New Mexico log grades. In addition, grades based only on log diameter were evaluated for each of the four data groups.

Data within each group were analyzed using analysis of variance and linear regression techniques. The four dependent variables examined were: (1) value of lumber from a log or tree per 100 cubic feet (2.83 m^3) of gross volume, (2) value of lumber from a log or tree per thousand board feet gross Scribner log scale, (3) percent of No. 2 Common and Better 4/4 lumber recovered from a log or tree, and (4) percent of No. 2 and Better 8/4 lumber recovered from a log or tree. The independent variables were the modified grades from Bailey, and the d.b.h. for trees or the small end diameter for logs.

No statistical analysis was made on several other variables for which data were taken and which are included in tables 5 and 7 for the reader's general information.

Analysis of variance (AOV) was applied to the data using the modified grades, or diameter, as the independent variable. Where the results of the AOV were significant, the practical inference is that grade, the independent variable, was an important determinant of value for the particular dependent variable.

Because the modified tree and log grades are closely related to diameter, the authors also investigated how diameter alone separates trees and logs into value classes. Thus, a statistically significant regression would support the hypothesis that the diameter of a tree or log could function as a single determinant of its quality or value.

Results and Discussion

At both sites, about half of the trees initially selected as grade 3 trees proved to be complete culls when felled. These trees were omitted from the mill sample and are not included in data summaries. This raises serious questions as to the adequacy or accuracy of the tree grade 3 criteria and indicates that supplementary techniques will be required to identify cull trees in cruising.

Tree Grades in Utah

Utah trees ranged in d.b.h. from 8 to 16 inches. The value per cunit of individual trees varied from $43 to $81, with an average value per cunit for all trees of $62. The AOV showed that tree grade did not conclusively separate trees into value classes based on dollars per cunit (table 5). The Utah mill mainly produced two distinctive products—mine posts from logs smaller than 10 inches in diameter and dimension lumber from logs 10 inches or larger in diameter. This distinction is important when interpreting the Utah data.

The value per gross thousand board feet of individual trees varied from $79 to $263. The mean values for each tree grade differed significantly from the others (table 5). It should be noted, however, that the value per gross thousand board feet increases with poorer grades. This is opposite to the relationship normally expected, and is explained by the fact that mine posts, a relatively high value product permitting wane and no

[5]*The dog board is the last board on the carriage in which the dogs (clamps) are inserted to hold the log during sawing.*

Table 5.—Summary of tree grade data for aspen in the Rocky Mountains

	Utah			New Mexico		
	1	2	3	1	2	3
Number of trees	6	17	11	9	24	19
Average value of trees, \$/Cunit[1] (dollars per 2.83m[3])	[2](57	64	62)	(92)	(74)	(55)
Average value of trees, dollars per gross thousand board feet (scribner log scale for merchantable trees	(106)	(141)	(206)	(163	148	135)
Average yield, No. 2 and Better dimension (percent of total lumber tally)	(42	29)	(10)			
Average yield, 4- by 6-inch (10- by 15-cm) mine posts (percent of total lumber tally)	6	24	56			
Average yield, No. 2 Common and Better (percent of total lumber tally)				(19)	(9	6)
Average yield, No. 3 Common and Better (percent of total lumber tally)				67	51	46

[1]*Value of trees in dollars per Cunit (100 gross cubic feet) refers to those trees processed at the mill and does not include trees culled in the woods.*

[2]*Means separated by parentheses are significantly different, at the 95% statistical confidence level, than other means in the same group of three. No parentheses for a group indicates that no analysis was made.*

ecessarily reflecting grade quality, were sawn from ae smaller trees. Many of these smaller trees are in rade 3, boosting recovery volume and value for this rade. This inverse effect is readily apparent when ecovery for each product is compared on a tree grade asis (table 6).

The proportion of No. 2 and Better dimension lumber ecovered, based on total lumber tally from individual ees, ranged from 0% to 67%. Most volume recovery dimension lumber was from grades 1 or 2 trees able 5). Smaller trees were mostly sawn into mine nbers (table 5).

ee Grades in New Mexico

Tree d.b.h. for the New Mexico sample ranged from 8 o 17 inches. The value per cunit for individual New exico trees that yielded at least one 8-foot log ranged om \$26 to \$122. The differences in mean value for ech tree grade were statistically significant, increasi as expected with better grades (table 5).

The value per gross thousand board feet of individul trees ranged from \$58 to \$285. The average lumber vue per gross thousand board feet was \$146. Mean vues were not significantly related to tree grade (tble 5). This is surprising in view of the significance ned in value per cunit. It probably resulted, especilly in grade 3, from the poor estimates of product vume with the Scribner scale at small diameters.

The proportion of No. 2 Common and Better boards from individual trees, based on the total merchantable lumber recovered, ranged from 0% to 51%. The average recovery for grade 1 was significantly higher than for grades 2 or 3 (table 5).

Log Grades in Utah

Eight-foot logs from Utah ranged from 5 to 14 inches in small-end diameter. The value per cunit for logs ranged from a low of \$3 for one typical grade 2 log to \$130. The average value per cunit was \$63. Log value per cunit was not significantly related to grade (table 7).

The value per gross thousand board feet of individual logs ranged from \$10 to \$470; the average value was \$162. This large spread results from the relatively high value and volume recovery for mine posts. Also,

Table 6.—Proportion of lumber recovered by tree grade and product, Utah data

Tree grade	Diameter class range	Dimension lumber	Mine props
	inches	*percent*	
1	14-16	94	6
2	10-14	76	24
3	8-12	44	56

Table 7.—Summary of log grade data for aspen in the Rocky Mountains

	Utah			New Mexico		
	1	2	3	1	2	3
Number of logs	70	61	20	132	91	10
Average value of logs, dollars per Cunit[1] (2.83m^3)	[2](64	63	56)	(81)	(58)	(42)
Average value of logs, dollars per gross thousand board feet (lumber tally) Scribner log scale	(148	177	167)	(166	156	125)
Average yield of No. 2 and Better (2 inch lumber compared with total yield, percent)	(36)	(19	13)			
Average yield of No. 3 and Better (2-inch lumber compared with total yield, percent)	65	47	25			
Average yield of No. 2 Common and Better (1-inch lumber compared with total yield, percent)				(12)	(4	0)
Average yield of No. 3 Common and Better (1-inch lumber compared with total yield, percent)				61	45	8
Average lumber recovery (log volume converted to lumber, percent)	50	52	56	49	20	38
Average chippable residue recovery (log volume converted to chips, percent)	38	39	41	36	47	51

[1]Value of logs in dollars per cunit (100 gross cubic feet).

[2]Means separated by parentheses are significantly different, at the 95% statistical confidence level, than other means in the same group of three. No parentheses for a group indicates that no analysis was made.

because of the special situation with respect to mine posts, value per gross thousand board feet was not significantly related to log grade (table 7).

The proportion of No. 2 and Better dimension lumber from individual logs ranged from 0% to 100%. The grade recovery from grade 1 logs was significantly higher than the recovery from grades 2 and 3 logs (table 7).

Log Grades in New Mexico

Eight-foot logs from New Mexico ranged from 5 to 16 inches in small-end diameter. The value of lumber per cunit from individual logs ranged from $6 to $148, with an average value of $70. The mean values for each grade were significantly different (table 7).

The value per gross thousand board feet of individual logs ranged from $16 to $412; the mean value was $160. There was no significant relationship to grade (table 7).

The proportion of No. 2 Common and Better boards from individual logs ranged from 0% to 68%. Grade 1 logs had significantly more recovery than grades 2 or 3 logs (table 7). Although the largest recovery value for individual logs is 68%, many logs yielded no boards graded No. 2 Common and Better; therefore, the mean values are low.

Diameter Alone as a Grade

Each of the independent variables in this study—the modified Bailey grades and diameter, both as a continuous and discrete variable—was evaluated on the basis of how much variation in the dependent variable is explained by the independent variable. A sum of squares analysis (table 8) was the technique for this evaluation. From the information in table 8, it appears that tree diameter grades function as well as the modified Bailey tree grades that incorporate both diameter and other quality factors. However, diameter lone was not an effective variable for separating logs nto various quality or value groups.

Summary and Conclusion

The log and tree grades evaluated in New Mexico for spen being sawn primarily into 1-inch lumber were omewhat effective in separating logs and trees into istinct value and recovery classes. Only the value per unit, however, reflected a statistical difference beween all grades.

able 8.—Proportion of total sums of squares (in percent) explained by classification of the sample data by grade or by diameter alone

	Grade groups, AOV	Diameter groups, AOV	Diameter, regression
tah trees			
Value per cunit, dollars	NS[1]	NS	NS
Value per gross thousand board feet, dollars	51	58	55
Percent No. 2 and Better	28	32	52
ew Mexico trees			
Value per cunit, dollars	NS	NS	NS
Value per gross thousand board feet, dollars	48	51	42
Percent No. 2 and Better	18	33	23

[1]Significance was determined both at the 5% and the 1% conidence levels. NS means not significantly different at either of ese levels.

In Utah, tree grades also worked well for separating trees by recovery classes and by dollar value per gross thousand board feet lumber tally when mine timbers and 2-inch lumber were sawn, but tree grades did not work well for separating trees by value per cunit. Log grades worked well only for separating logs into dimension lumber recovery classes. They did not work well when mine props, a nongrade item, were the main product. As indicated previously, the results from Utah reflect the somewhat unique situation in which mine timbers, a relatively high value product permitting wane, were sawn from the smaller, lower grade trees instead of boards or dimension lumber. This product, which raised recovery volumes and values from the lower log grades, is not adequately reflected in the modified grading system.

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Agriculture—CSU, Fort Collins

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Wengert, Eugene M. and Dennis M. Donnelly. 1980. Lumber yield potential of aspen in the Rocky Mountains. USDA Forest Service Research Paper RM-227, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

The yield of sawn products from aspen (*Populus tremuloides* Michx.) trees from northern New Mexico and eastern Utah, both in terms of volume and dollar value, was related to trial tree and log grades. Trial grading systems generally allowed separation of trees and logs into different levels of volume and dollar value recovery.

Keywords: Lumber yield, aspen, *Populus tremuloides* Michx., Rocky Mountains, forest products

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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United States
Department of
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Forest Service

**Rocky Mountain
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Experiment Station**

Fort Collins
Colorado 80526

Research Paper
RM-228

Management of Ponderosa Pine in Even-Aged Stands in the Black Hills

Robert R. Alexander
Carleton B. Edminster

Abstract

Potential production of ponderosa pine in the Black Hills is simulated for various combinations of stand density, site index, age, and thinning schedule. Such estimates are needed to project future development of stands managed in different ways for various uses.

Cover Photo.—Second-growth Black Hills ponderosa pine on an average site thinned to GSL 60. Stand now averages 6.7 inches d.b.h., was first thinned in 1963, and was rethinned in 1973.

USDA Forest Service
Research Paper RM-228

April 1981

Management of Ponderosa Pine in Even-Aged Stands in the Black Hills

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Rocky Mountain Forest and Range Experiment Station[1]

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Contents

Management of Ponderosa Pine in Even-Aged Stands in the Black Hills

Robert R. Alexander and Carleton B. Edminster

Silviculture of Black Hills Ponderosa Pine

Black Hills ponderosa pine (*Pinus ponderosa* Laws) cover type occupies about 1 million acres in the Black Hills of South Dakota and Wyoming, and associated Bear Lodge Mountains of Wyoming. These forests form a unique, isolated segment of the interior ponderosa pine type. Ponderosa pine is the principal timber species, and usually occurs in pure stands (Alexander 1974, Boldt and Van Deusen 1974). The main timber-producing areas are the crystalline core area, which is characterized by rough to rounded hills and divides generally ranging from 4,300 to 6,000 feet elevation, and the limestone plateau. In the east, the plateau forms a narrow ridge that occasionally flattens out to narrow uplands with elevations of 3,600 to 4,400 feet; in the west, it forms wide, rather level divides separated by narrow, steep valleys that range in elevation from 4,500 to 7,000 feet.

Ponderosa pine forests in the Black Hills have provided a variety of wood products since they were first cut beginning in the mid-1870's. During the past century, virtually all of the area's unreserved and operable forest acres have been cut over once; and many acres have received multiple partial cuts. Large tracts which were logged free of regulatory restraints—before establishment of the Forest Reserve in 1897—were commercially clearcut and literally stripped of all trees large enough to produce a railroad tie or mine timber (Boldt and Van Deusen 1974).

The long history of cutting, together with losses caused by insects, diseases, winds, and fires, has nearly eliminated the original old-growth sawtimber stands on about one-half of the commercial forest area. Only light stands of scattered, old-growth remnants are left on the remaining acres (Boldt and Van Deusen 1974). Despite all of the harvesting and losses to destructive agents, growing stock has not been seriously depleted.

Black Hills ponderosa pine forests have produced large quantities and varied kinds of wood products. They have also provided forage for livestock and big game, habitats for a variety of other wildlife, water for domestic, industrial and agricultural uses, and recreational opportunities for millions of people. Today, all of these demands on the forest are increasing, and how the Black Hills ponderosa pine forests are managed will affect all resources and uses. For example, if timber production is the primary objective, growing stock levels (GSL)[2] should be high, but forage production and water yields can be substantially increased only at low GSL's. Carefully planned harvests that maintain low to medium growing stock levels are generally considered appropriate to improve developed recreational opportunities and enhance foreground esthetics. Improvement of middleground and background esthetics generally require open forests, and both low and high growing stock levels to provide contrasts. Wildlife habitat requirements vary from uncut to open forests.

Although land-use planners and land managers must increasingly direct their efforts toward multiple uses, these practices must be based on sound silvicultural principles of the forest type involved. They must understand the tradeoffs between the timber resource and other physical, social, and economic considerations.

Black Hills ponderosa pine has been managed longer and more intensively than any other Rocky Mountain timber type. Regeneration silviculture has been learned by experience during a century of harvesting that has included all even- and uneven-aged cutting methods, and has led to the conversion of old-growth stands to well-stocked, manageable stands of second-growth, with little or no reduction in productivity. Management of Black Hills ponderosa pine is somewhat simplified because these forests reproduce readily and prolifically, and are free of dwarf mistletoe.

Today, managers are not only concerned with prompt restocking of cutover areas with new reproduction, but also (1) increasing the growth rate of the new stand by control of stand density, and (2) improving quantity and quality of yields by periodic thinning to maintain stocking control and growth rates, and to reduce mortality. Under intensive management, annual net increment for Black Hills ponderosa pine can be expected to be from 100 to 300 fbm per acre, depending

[2]Growing stock level (GSL) is defined as the residual square feet of basal area per acre when average stand diameter is 10 inches or more. Basal area retained in a stand with an average diameter of less than 10 inches is less than the designated level (Myers 1971, Edminster 1978). Tables A-1, A-2, and A-3 give the number of trees, basal area, and square spacing for stands with average diameters after thinning of 2 to 10 inches, for GSL's 40 to 160.

upon growing stock level, site index, rotation age, and cutting cycle (Edminster 1978).

Control of stand density offers the greatest opportunity for increasing wood production by increasing growth and reducing mortality, but harvested stands must be replaced promptly to reduce the time required to reach maximum yields. However, stumpage values will have to improve in the Black Hills before the manager can do the cultural work required to increase timber production.

Establishment of Regeneration

Black Hills ponderosa pine is most easily maintained as a vigorous, productive forest under even-aged management. Shelterwood is the best cutting method for most ponderosa pine condition classes (Boldt 1973, Boldt and Van Deusen 1974). It takes advantage of the species' natural habit of forming even-aged stands and provides continuous overstory protection of the site, which retards development of competing understory vegetation, while providing a well-distributed source of seed. A uniform, two-cut shelterwood is preferred, but a three-cut shelterwood can be used in very heavily stocked, mature stands where risk of logging residue buildup, windfall risk, and logging damage to established regeneration are likely to be high. Seed-tree and clearcutting methods have been used in the Black Hills, but both risk loss of seed source, provide little control of competitive understory vegetation, and generate large amounts of logging residue. Uneven-aged management is generally inappropriate for regeneration, but uneven-aged management cutting methods may be appropriate for multiple use (Alexander 1974, Boldt and Van Deusen 1974). They are not discussed in this paper, because suitable growth and yield prediction tools are not available for managed, uneven-aged, Black Hills ponderosa pine stands.

Ponderosa pine usually regenerates readily and abundantly under even-aged management, within a short time after the seed or final cut. There is some variation among habitat types, however. Ordinarily, only the absence or loss of seed source results in poorly stocked or non-stocked areas that must be regenerated artificially. Boldt and Van Deusen (1974) summarized guidelines for planting and direct seeding. If areas are not adequately stocked within 5 years after final harvest, the manager must take action under the regulations of the National Forest Management Act of 1976 to artificially restock the areas.

Boldt and Van Deusen (1974) recommend planting 500 to 800 trees per acre. The minimum number suggested should provide sufficient number of stems when the average diameter of the stand reaches 5 inches d.b.h. for GSL's up to 80. However, if Black Hills ponderosa pine is to be managed at higher GSL's, a minimum 800 trees per acre should be planted, and 1,000 to 1,200 trees per acre would provide the manager with a better choice of crop trees when the stand average diameter reaches 5 inches d.b.h.

Need for Early Precommercial Thinning

Establishing a new stand is only the beginning. Trees must have room to grow to reach merchantable size. In the Black Hills, extremely high densities are common in naturally regenerated stands. Dense seedling stands often contain more than one tree per square foot. Because natural thinning normally proceeds very slowly, an initially crowded stand may remain overstocked for its entire life (Boldt and Van Deusen 1974). For example, on one plot in the Black Hills, stand density was 15,000 stems per acre at age 12 years. At age 63 years, it still contained 6,600 trees per acre, with an average stand diameter of only 2.4 inches d.b.h. (Myers and Van Deusen 1960). More than one-half of a 120-year rotation has passed without any usable wood production. For acceptable growth rates under these dense conditions, precommercial thinning is needed to reduce stand density to 800 to 1,200 stems per acre during the first 10 years of the life of the stand.

When enough seedlings become established within 5 years after the seed-cut of a shelterwood method, the removal cut should be made promptly to avoid suppression of the new stand. Care must be exercised to avoid excessive damage to the established reproduction, otherwise the new stand may not adequately restock.

Estimates of Growth Under Intensive Management

Intensive management of Black Hills ponderosa pine forests provides many opportunities for increasing usable wood production, but estimates of future stand development under various management regimes are needed.

Information available on the growth of ponderosa pine from sapling stage to final harvest, under even-aged management, with a shelterwood cut, is provided by field and computer simulation procedures developed by Myers (1971) and refined by Edminster (1978). The procedures were developed from field data on past growth related to stand density, age, and site quality. Data were obtained from a large number of both permanent and temporary plots established in thinned and natural stands throughout the Black Hills.

The modeling concept used in these programs holds that the whole stand is the primary model unit, as characterized by average values. The equations upon which the growth and yield simulations are based are given in Myers (1971). The programs project stand development by consecutive, 10-year projection periods, with relationships to project average stand diameter, average dominant and codominant height, and number of trees per acre. Average diameter at the end of a projection period is a function of average diameter at the beginning of the period, site index, and basal area per acre. Periodic average dominant and codominant height growth at managed stand densities is a function of age and site index. Periodic mortality is a function of average diameter and basal area per acre. Stand volume equations are used to compute total cubic feet per acre; factors are computed to convert this to merchantable cubic feet and board feet. Prediction equations are included to estimate the effects of differing intensities of thinning from below on average diameter, average dominant and codominant height, and trees retained per acre.

Yield simulations discussed in the following paragraphs were made to the same hypothetical initial stand conditions for all growth parameters:

1. Average age at first GSL thinning is 30 years.
2. Average stand diameter is 4.5 inches d.b.h.[3]
3. Stand density is 1,000 trees per acre.
4. Site index is 50-, 60-, 70-, and 80-foot classes, at base age 100 years (Meyer 1961)
5. Projections were made for 50 years (stand age 80 years) and 90 years (stand age 120 years)
6. Thinnings from below were made every 20 and 30 years to growing stock levels (GSL) of 40, 60, 80, 100, 120, 140, and 160, with initial and subsequent entries made to the same growing stock level
7. A two-cut shelterwood option was used. The seed cut was made 20 years before the final cut and retained 50% of the subsequent GSL.
8. Minimum size for inclusion in board foot volume determination was 10 inches d.b.h. to an 8-inch top. Volumes were determined from tables prepared by Myers (1964).[4]
9. All entries were made as scheduled even though all thinnings could be precommercial.

Diameter Growth

Periodic mean annual diameter growth of Black Hills ponderosa pine is related to stand density and site quality, but is affected little by the cutting cycles tested. Cutting cycles do influence average stand diameter, however, because thinning from below increases average diameter at each entry. Actual basal area in a stand with an average diameter of less than 10 inches d.b.h. continues to increase, because periodic thinning does not reduce basal area to a fixed (GSL) amount until an average stand diameter of 10 inches d.b.h. is reached. Consequently, the rate of diameter growth for a given GSL is not constant over time, and is essentially a negative exponential function of basal area per acre in the program. In contrast, periodic diameter growth is a linear function of site index, so that differences in diameter growth resulting from site quality are constant throughout the range of GSL's and rotations examined.

Growth rates and changes in diameter resulting from thinning frequency were examined to determine average size of trees relative to rotation age. With a 20-year cutting cycle, for example, trees reach average stand diameters of 10.2 to 18.3 inches d.b.h. after 80 years, and 12.6 to 26.9 inches d.b.h. after 120 years for the range of GSL's and site indexes tested (table 1). On an average site (index 70), with a 20-year cutting cycle, mean stand diameters reached 10 inches d.b.h. at about 50 to 90 years of age for the range of GSL's 40 to 160 (fig. 1).

Height Growth

Periodic mean annual height growth of ponderosa pine increases with site index and decreases with age, but is unaffected by GSL's, cutting methods, or the cutting cycles examined. However, since fewer and, therefore, taller trees are left after each thinning from below, the mean height of the dominant and codominant trees is increased slightly at each entry. The increase is positively correlated with thinning frequency and negatively correlated with GSL.

Basal Area Growth

Periodic mean annual basal area increment is related to growing stock level, site quality, frequency of thinning, and rotation age. Because actual basal area continues to increase in a stand until average stand diameter reaches 10 inches d.b.h. and thinning reduces basal area to a fixed amount (GSL), the rate of basal area growth for a given GSL is not constant over time. Periodic basal area increment increases as growing stock level increases from 40 to 140, but the rate of increase diminishes as stand density increases. At GSL's above 140, basal area increment declines on all sites. Periodic mean basal area growth also increases as site index increases. Moreover, the differences in basal area growth between site classes become progressively greater as GSL increases. Periodic mean basal area increment is greater with a 30-year cutting cycle than with a 20-year entry at all rotations examined, for GSL's 40 to 140.

Total Cubic-Foot Volume Increment

Cubic-foot volume production is related to stand density, site quality, rotation age, and frequency of thinning (table 2). Although mean annual cubic volume increment increases as growing stock level and site index increases, the rate of increase diminishes as GSL increases, while the differences in growth between site classes becomes greater (fig. 2) (table 3). Cubic volume increment for both rotations examined will apparently continue to increase at GSL's above 160 on site index 70 and 80 lands, but level off or decline on site index 50 and 60 lands at GSL's greater than 160. Mean annual cubic volume increment is generally greater with a 120-year rotation and a 30-year cutting cycle for all GSL's and site indexes examined.

[3]Average diameter is the diameter of the tree of average basal area; it is not the average of all the tree diameters.

[4]Utilization standards in the Black Hills for board-foot volume determination are changing to 8 inches d.b.h. to a 6-inch top. Estimates of board-foot volume growth and production in this paper may be slightly lower than actual board foot volumes because of the change in utilization standards.

Table 1.—Estimated average diameter (inches) and number of trees per acre of Black Hills ponderosa pine at final harvest in relation to growing stock level, rotation age, cutting cycle, and site index

		Growing stock level													
		40		60		80		100		120		140		160	
Rotation age	Cutting cycle	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter
								Site Index 50							
80	20	22	16.5	39	14.8	64	13.3	92	12.3	119	11.5	153	10.8	189	10.2
120		9	23.7	18	20.6	29	18.5	46	16.4	63	15.3	89	13.9	123	12.6
80	30	24	15.9	45	14.1	72	12.7	101	11.7	131	11.0	165	10.4	202	9.8
120		10	22.9	20	19.6	33	17.6	50	15.9	67	14.9	94	13.6	128	12.4
								Site Index 60							
80	20	21	17.0	38	15.3	60	13.9	83	13.0	111	12.1	145	11.3	180	10.7
120		9	24.4	17	21.5	27	19.4	40	17.6	56	16.3	77	15.0	105	13.7
80	30	23	16.4	42	14.6	67	13.2	92	12.4	124	11.5	155	10.9	192	10.3
120		10	23.5	18	20.7	30	18.5	45	16.7	62	15.6	82	14.6	109	13.5
								Site Index 70							
80	20	20	17.5	36	15.8	55	14.5	80	13.3	106	12.6	132	12.0	168	11.2
120		8	25.4	15	22.5	25	20.2	37	18.5	52	17.1	66	16.2	90	14.9
80	30	21	17.1	39	15.2	63	13.8	90	12.7	120	11.9	147	11.4	183	10.9
120		9	24.8	17	21.7	28	19.2	41	17.6	56	16.5	74	15.5	99	14.3
								Site Index 80							
80	20	18	18.3	34	16.4	53	15.0	77	13.7	100	13.1	130	12.3	154	11.9
120		7	26.9	14	23.5	22	21.4	34	19.4	46	18.2	62	16.9	79	15.9
80	30	20	17.7	37	15.8	61	14.1	85	13.2	110	12.6	142	11.8	174	11.2
120		8	25.8	15	22.7	25	20.4	38	18.5	50	17.5	68	16.2	87	15.3

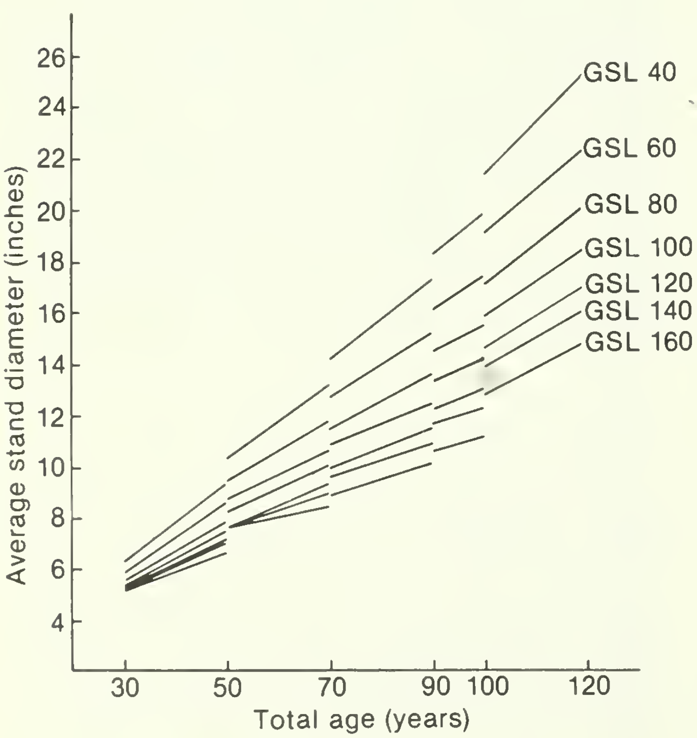
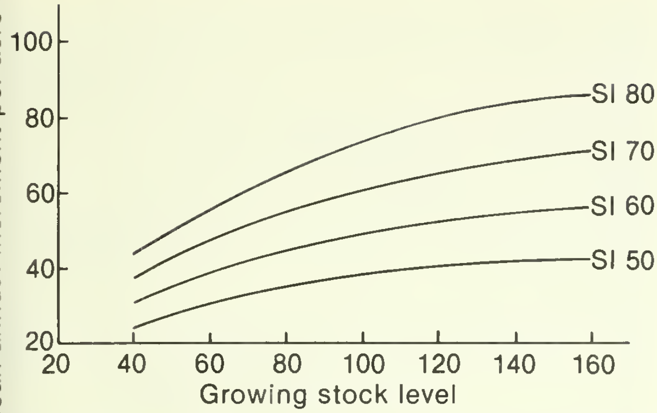


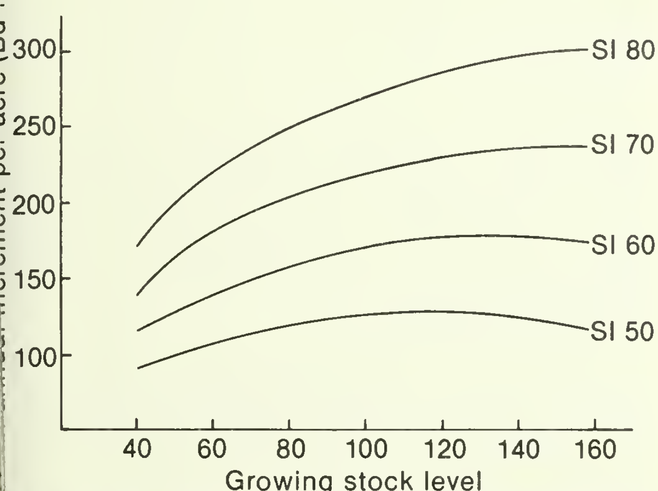
Figure 1.—Estimated average stand diameter of Black Hills ponderosa pine in relation to age and GSL on site index 70 lands, with a 20-year thinning interval.

Table 2.—Estimated total cubic-foot volume production per acre, of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index

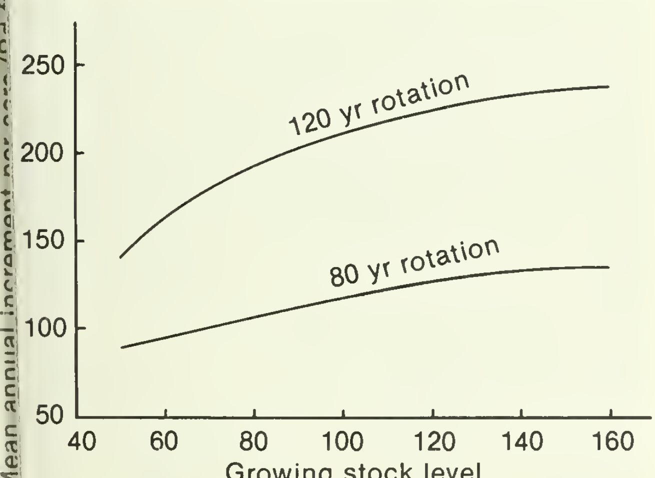
Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
— years —		— thousand cubic feet —						
		Site Index 50						
80	20	1.91	2.24	2.55	2.80	2.96	3.04	3.12
120		2.95	3.67	4.20	4.56	4.82	4.94	5.04
80	30	2.04	2.37	2.63	2.80	2.96	3.10	3.19
120		3.10	3.80	4.33	4.66	4.91	5.02	5.10
		Site Index 60						
80	20	2.39	2.90	3.32	3.61	3.83	3.97	4.06
120		3.71	4.62	5.30	5.88	6.24	6.48	6.67
80	30	2.56	3.02	3.38	3.66	3.90	4.12	4.20
120		3.90	4.81	5.56	6.12	6.50	6.82	6.98
		Site Index 70						
80	20	2.94	3.50	4.02	4.44	4.78	5.01	5.13
120		4.48	5.62	6.48	7.19	7.75	8.22	8.46
80	30	3.12	3.72	4.19	4.55	4.81	5.06	5.20
120		4.73	5.90	6.84	7.56	8.16	8.53	8.84
		Site Index 80						
80	20	3.50	4.29	4.88	5.32	5.68	5.96	6.16
120		5.26	6.70	7.85	8.78	9.54	9.97	10.26
80	30	3.76	4.42	5.01	5.49	5.82	6.03	6.20
120		5.63	7.04	8.18	9.12	9.86	10.43	10.70



igure 2.—Estimated mean annual total cubic-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level for a 120-year rotation with a 20-year thinning interval.



igure 3.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level for a 120-year rotation with a 20-year thinning interval.



F ure 4.—Estimated mean annual board-foot volume increment er acre of Black Hills ponderosa pine on site index 70 lands ith a 20-year thinning interval in relation to GSL and rotation ge.

Table 3.—Estimated mean annual total cubic-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		*cubic feet*						
		Site Index 50						
80	20	23.9	28.0	31.9	35.0	37.0	38.0	39.0
120		24.6	30.6	35.0	38.0	40.2	41.2	42.0
80	30	25.5	29.6	32.9	35.0	37.0	38.8	39.9
120		25.8	31.7	36.1	38.8	40.9	41.8	42.5
		Site Index 60						
80	20	29.9	36.2	41.5	45.1	47.9	49.6	50.9
120		30.9	38.5	44.2	49.0	52.0	54.0	55.6
80	30	32.0	37.8	42.2	45.8	48.8	51.3	52.5
120		32.5	40.1	46.3	51.0	54.2	56.8	58.2
		Site Index 70						
80	20	36.8	43.8	50.2	55.5	59.8	62.6	64.1
120		37.3	46.8	54.0	59.9	64.6	68.5	70.5
80	30	39.0	46.5	52.4	56.9	60.1	63.2	65.0
120		39.4	49.2	57.0	63.0	68.0	71.1	73.7
		Site Index 80						
80	20	43.8	53.6	61.0	66.5	71.0	74.5	77.0
120		43.8	55.8	65.4	73.2	79.5	83.1	85.5
80	30	47.0	55.3	62.6	68.6	72.8	75.4	77.5
120		46.9	58.7	68.2	76.0	82.2	86.9	89.2

Table 4.—Estimated total board-foot volume production per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index (trees 10 inches d.b.h. and larger to an 8-inch top)

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		*thousand board feet*						
		Site Index 50						
80	20	4.40	4.88	5.28	5.52	5.60	5.36	4.96
120		11.04	12.96	14.28	15.12	15.36	14.88	13.80
80	30	4.32	4.88	5.04	5.20	5.04	4.72	4.16
120		11.04	13.20	14.28	14.88	15.00	14.04	12.60
		Site Index 60						
80	20	5.68	6.40	7.12	7.68	7.84	7.84	7.52
120		13.92	16.80	18.84	20.16	21.24	21.36	20.64
80	30	5.92	6.40	6.72	6.96	7.04	6.96	6.72
120		14.28	16.92	18.84	20.16	20.88	20.64	19.92
		Site Index 70						
80	20	7.20	8.08	8.96	9.76	10.40	10.64	10.64
120		16.80	21.48	24.36	26.16	27.60	28.08	28.20
80	30	7.68	8.48	8.96	9.28	9.60	9.76	9.76
120		18.12	21.84	24.60	26.76	27.84	28.20	28.32
		Site Index 80						
80	20	8.88	10.24	11.36	12.32	13.20	13.76	14.08
120		20.64	26.04	29.64	32.16	34.20	35.64	35.88
80	30	9.76	10.88	11.60	12.16	12.64	12.80	12.96
120		22.32	26.64	29.88	32.52	34.32	35.64	36.00

Board-Foot Volume Increment

Board-foot volume production is related to all stand parameters evaluated (table 4). Mean annual sawtimber volume growth increases on site index 70 and 80 lands as stand density increases from GSL 40 to 140. Above GSL 140, growth begins to level off. On site index 50 and 60 lands, growth generally levels off or declines at GSL's above 120 (fig. 3) (table 5).

Board-foot volume growth increases with site quality, and the differences in growth between site classes become greater as GSL increases. Throughout the range of GSL's tested, average annual board-foot increment per acre is always greater for all site classes on a 120-year rotation (fig. 4). There are no practical differences in board-foot volume growth between 20- and 30-year cutting cycles for the range of site indexes and GSL's tested (fig. 5) (table 5).

Maximizing Board-Foot Volume Yields

What yields can be expected with intensive management of Black Hills ponderosa pine to maximize timber production? If the objective is to integrate timber production with other resources uses, what are the timber tradeoffs? How can these objectives be attained with the fewest precommercial thinnings?

The largest volume production per acre (about 36,000 fbm) is attained on site index 80 lands, at GSL's 140 to 160, on a 120-year rotation, with either a 20- or a 30-year cutting cycle (table 4). These stands will contain between 60 and 90 trees per acre, with an average diameter of between 15 and 17 inches d.b.h. at rotation age (table 1).

Maximum volume production on site index 70 lands is also at GSL's 140 to 160. Volume production declines substantially when GSL is reduced below 140 on site index 70 and 80 lands. The decline is greater with each successive reduction in GSL. On site index 50 and 60 lands, the largest volume production occurs at GSL's 120 to 140 on a 120-year rotation with a 20-year cutting cycle (table 4) (fig. 6).

Table 4 also shows the amount of volume given up as GSL is reduced from the level of maximum production to 40 for all combinations of stand parameters examined. Moreover, it shows that more volume can be produced over the same time span with a 120-year rotation than with an 80-year rotation. For example, on site index 80 lands, at GSL's 140 to 160, average volume production per acre on two 120-year rotations or 240

Table 5.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index (trees 10 inches d.b.h. and larger to an 8-inch top)

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		*board feet*						
		Site Index 50						
80	20	55	61	66	69	70	67	62
120		92	108	119	126	128	124	115
80	30	54	61	63	65	63	59	52
120		92	110	119	124	125	117	105
		Site Index 60						
80	20	71	80	89	96	98	98	94
120		116	140	157	168	177	178	172
80	30	74	80	84	87	88	87	84
120		119	141	157	168	174	172	166
		Site Index 70						
80	20	90	101	112	122	130	133	133
120		140	179	203	218	230	234	235
80	30	96	106	112	116	120	122	122
120		151	182	205	223	232	235	236
		Site Index 80						
80	20	111	128	142	154	165	172	176
120		172	217	247	268	285	297	299
80	30	122	136	145	152	158	160	162
120		186	222	249	270	286	297	300

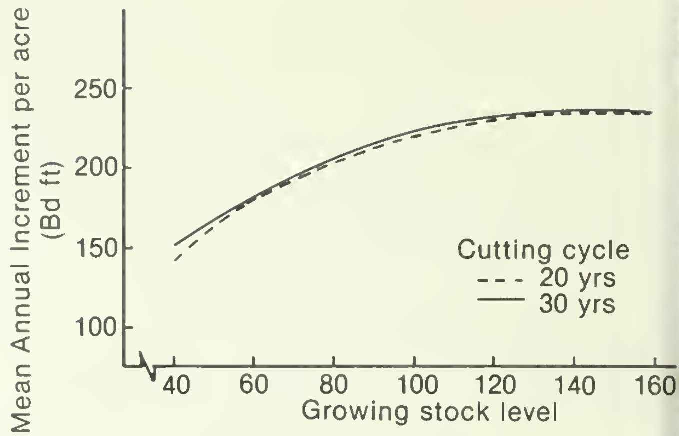


Figure 5.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine on site index 70 lands in relation to GSL and thinning interval.

Figure 6.—Second-growth Black Hills ponderosa pine on an average site thinned to GSL 120. Stand now averages 6.2 inches d.b.h., was first thinned in 1963, and was rethinned in 1973.

ears would be about 72,000 fbm, compared with about 0,000 fbm per acre on three 80-year rotations, also 40 years.

Whether the board-foot volume production poten- als can be achieved depends largely on how much ioney can be invested in thinning. We have assumed iat once a stand reaches a minimum size of 5 inches verage d.b.h., intermediate thinnings will be made as cheduled. If economic constraints limit managers to nly one precommercial thinning in the life of the and, their options are severely restricted. For ex- mple, on site index 50 lands, stand density must e reduced to GSL's 60 and the cutting cycle increased 30 years (table 6). On site index 60 and 70 lands, a SL of 100 can be maintained with a 30-year cutting ycle, and on site index 80 lands a GSL of 120 can be aintained.

Thinnings to a constant GSL have been assumed up now. However, if only one precommerical thinning is ossible, managers can increase their flexibility by hanging GSL's with successive reentries. For exam- le, on site index 70 lands, with a 30-year cutting cycle, and density is initially reduced to GSL 100. At the me of the second thinning, GSL is increased to 120, nd increased to GSL 140 with the third thinning. olume production will be less than maximum, but easonably close to the volume available from a stand aintained at a constant GSL 140. Attempts to raise e GSL to 140 at the time of the second entry into the and would result in a second precommercial thin- ng. By following this procedure, managers can in- ease GSL on site index 50 lands from 60 to 100.

The manager has another option if only one precom- ercial thinning is possible. The initial thinning can be ade on schedule and the second entry delayed until e stand reaches minimum merchantable size. This ill increase the thinning interval to 40 years or more, crease the length of rotation, and result in less than aximum volume production.

Where economic conditions permit investment of nds in two precommercial thinnings, the manager s the opportunity to maximize timber production at a nstant GSL 100 on site index 50 lands to GSL 140 on e index 80 lands with a 30-year thinning interval ble 6).

Managers also may elect to change GSL's with suc- ssive reentries regardless of the number of precom- rcial thinnings that are economically possible. With s procedure, the concern about retaining large mbers of trees early in the life of the stand and small mbers of trees later in the rotation can be avoided. r example, stand density can be initially reduced to L's 60 to 80 and successively increased to GSL's 100 140, depending upon site quality and cutting cycle. ume production would be less than if density were intained at a constant and higher initial GSL, vever.

adeoffs to Increase the Values of Other Resources

nderstory vegetation on Black Hills ponderosa pine fosted ranges is the potential food supply for many

Table 6.—Number of precommercial thinnings of Black Hills ponderosa pine in relation to growing stock level cutting cycle and site index

Cutting cycle	Site index	Growing stock level						
		40	60	80	100	120	140	160
– years –								
20	50	2	2	2	2	3	3	4
	60	2	2	2	2	3	3	3
	70	1	2	2	2	2	3	3
	80	1	2	2	2	2	3	3
30	50	1	1	2	2	2	3	3
	60	1	1	1	1	2	2	3
	70	1	1	1	1	2	2	2
	80	1	1	1	1	1	2	2

big game animals and livestock. Available forage is strongly influenced by timber overstory, however. Understory production is inversely related to overstory density (Pase 1958, Krantz and Linder 1973). Using the following regression model developed by Pase (1958):

$$\text{Log } y = 3.22260 - 0.00936x$$

where y = herbage production (pounds per acre)
x = basal area (square feet per acre)
Log = logarithm to base 10

forage production is estimated to vary from about 1,700 pounds per acre on clearcut areas to as little as 20 pounds per acre under dense stands (200 or more square feet basal area per acre) (fig. 7). With 80 square feet basal area, a common density for managed stands in the Black Hills, forage production is only about 300 pounds per acre. Forage production estimated by this equation is an average for the Black Hills; actual production will vary according to habitat type.

Severson and Boldt (1977) reported on the preliminary results of a study to measure overstory/understory production in sapling and pole-sized stands of Black Hills ponderosa pine, that had been thinned to GSL's 0, 20, 60, and 100, in 1963 and again in 1973. Their preliminary findings indicated that forage production was greatest under stands where GSL was reduced to 0 or 20. The combined production of wood and forage was greatest at GSL's 60 to 100, but no estimates of combined production were made at higher GSL's. This study, however, reports the results of only one measurement of changes in understory production in relation to overstory density. Consequently, these data cannot be used to quantify changes in forage production under Black Hills ponderosa pine for the range of GSL's, site indexes, cutting cycles, and rotation ages examined. However, some general conclusions can be drawn from the data provided by Pase (1958) and Severson and Boldt (1977). To increase herbage production to even moderate levels (400-500 pounds per

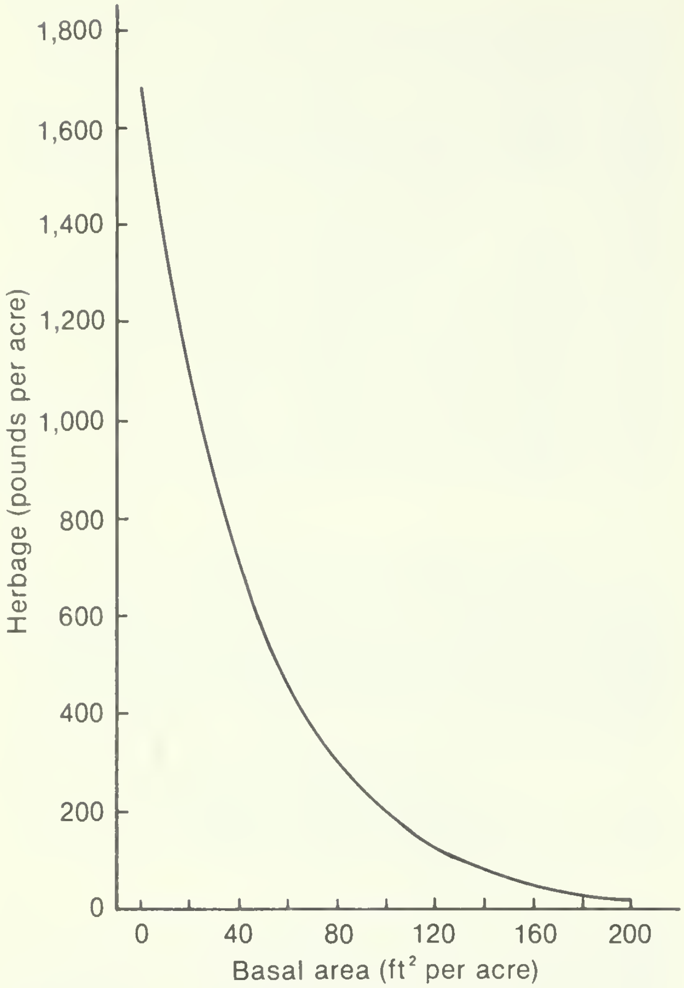


Figure 7.—Relation of herbage production to basal area of Black Hills ponderosa pine (Pase 1958).

acre depending upon habitat type), the manager must be willing to reduce basal area stocking to less than 60 square feet per acre (fig. 8). Moreover, to maintain this forage production, additional cuts must be made in pole-sized or larger stands at intervals of at least every 20 years.

Black Hills ponderosa pine forest areas yield more water than Southwestern or Front Range ponderosa pine forest areas (Gary 1975, Leaf 1975, Orr 1975). They yield less water than the subalpine forest areas in central Rocky Mountains with about the same amount of precipitation, because the distribution pattern is different and evapotranspiration demands of vegetation are higher during a longer and warmer growing season. About 25% of the precipitation is available for streamflow in the Black Hills. In the northern Black Hills, where precipitation is heaviest (average 28 inches), water yields from untreated pine forests, on the Sturgis watersheds, averaged about 7 inches from 1964 to 1969 (Orr and VanderHeide 1973). More than 90% of the annual runoff was produced by 52% of the annual precipitation, which falls during April to June. Winter snowfall is important to the recharge of soil moisture and to early runoff during the spring melt period, but it contributes little to total streamflow. Anderson (1980) reported average streamflow increases of 1.93 inches for 8 years after a partial cut on 50% of the Sturgis watershed. Increases were greatest during the wet years.

The potential for increasing streamflow in the Black Hills should be greater than the slightly more than 1 inch available from Southwestern and Front Range ponderosa pine. The most effective pattern of timber harvest for increasing water yields is to clearcut some portion of first order basins and interbasin areas in small irregular patches, provided that conveyance and other losses would be minimal (Leaf 1975, Orr 1975).

The increase in streamflow resulting from clearcutting is largely caused by reduced evapotranspiration. Redistribution of snow is less important in the Black Hills than in central Rocky Mountain subalpine forests (Leaf 1975). Not only is evapotranspiration reduced by removing trees in cleared patches, but soil moisture is fully recharged earlier in the growing season, resulting in more runoff and a longer runoff period than in uncut or partially cut stands (Orr 1968, 1975). The increase in water available for streamflow diminishes as understory vegetation becomes established. However, it will not return to pretreatment levels until the site is fully occupied by a new stand of trees.

Thinning second growth ponderosa pine also reduces soil moisture deficits, resulting in a greater potential for increased streamflow. But reducing basal area to 80 square feet, a common practice in the Black Hills, will result in less water available for streamflow than at stocking levels less than 60 square feet basal area per acre.

Based on information available from research, observation, and experience, stand density must be reduced and maintained at low stocking levels (less than 60 square feet basal area per acre) to substantially benefit forage and water resources. Foreground landscape esthetics and developed recreational opportunities are generally improved only at moderate den-

Figure 8.—Second-growth Black Hills ponderosa pine on an average site thinned to GSL 40. Stand now averages 7 inches d.b.h., was first thinned in 1963, and was rethinned in 1973.

ties (GSL 60 to 100). However, considerable timber olume is given up at low growing stock levels on the etter sites. For example, on site index 70 lands, at GSL 0, with a 120-year rotation and a 30-year thinning chedule, 3,600 fewer fbm per acre will be produced ıan with GSL 140. If GSL is reduced to 40, the loss in olume production is 10,080 fbm per acre (table 4).

Mountain pine beetles (*Dendroctonus ponderosae* opkins) have devastated unmanaged ponderosa pine, articularly the dense second-growth, essentially even-ged stands, in the northern Black Hills. Severe tree-lling has been associated with stand densities rang-g from 150 to 260 square feet basal area per acre, nd mean tree diameters of about 11 inches d.b.h. artwell and Stevens 1975). The relationship between ountain pine beetle populations, individual ponder-sa pine susceptibility, and stand density have not een determined where density has been controlled for e life of the stand. However, it is not unreasonable to elieve that managed stands maintained at GSL's 100 140, which are below the densities of unmanaged ands most often attacked, will not be as susceptible to eetles.

Middleground and background landscape esthetics quire combinations of openings, high and low stock-g levels, and uncut timber to provide the variety and ontrast that is visually pleasing. The habitats of most ildlife species are affected by changes in vertical and orizontal stand structures resulting from timber arvest. Some wildlife species require openings or the mbination of openings and high forests, others re-iire open-standing trees, while the habitat of some ildlife species is devastated by any kind of cutting. ıt until the habitat requirements of specific wildlife ecies are better known, the benefits and losses to ldlife associated with the stand parameters exam-ed here cannot be determined.

Management Caution

This simulation program estimates growth responses different stand parameters that appear reasonable d consistent within limits of present knowledge, but Black Hills ponderosa pine stand has been under the d of management envisioned here for long periods of e, and simulation extends beyond the limits of the ilable data base. Comparisons of estimates with ac-l values from plots established to provide growth in-mation will be needed to verify simulated responses.

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Appendix

Table A-1.—Basal areas (square feet per acre) after thinning in relation to average stand diameter (inches d.b.h.) and growing stock level

Ave. stand d.b.h. after cutting	Growing stock level										
	40	50	60	70	80	90	100	110	120	140	160
2.0	6.0	7.5	9.1	10.6	12.1	13.6	15.1	16.7	18.2	21.2	24.2
3.0	11.8	14.8	17.7	20.6	23.6	26.6	29.5	32.4	35.4	41.5	47.4
4.0	17.6	22.0	26.4	30.8	35.2	39.6	44.0	48.4	52.8	61.6	70.4
5.0	23.4	29.2	35.0	40.9	46.7	52.5	58.4	64.2	70.0	81.9	93.6
6.0	28.3	35.4	42.4	49.5	56.6	63.7	70.8	77.8	84.9	99.0	113.2
7.0	32.7	40.9	49.1	57.3	65.5	73.7	81.9	90.1	98.2	114.4	130.8
8.0	36.2	45.3	54.4	63.4	72.5	81.6	90.6	99.7	108.8	126.9	145.0
9.0	38.8	48.4	58.1	67.8	77.5	87.2	96.9	106.6	116.2	135.6	155.0
10.0 +	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	140.0	160.0

Table A-2.—Number of trees per acre after thinning in relation to average diameter (inches d.b.h.) and growing stock level

Ave. stand d.b.h. after thinning	Growing stock level										
	40	50	60	70	80	90	100	110	120	140	160
2.0	277	345	418	488	553	626	692	767	836	968	1,107
3.0	241	301	360	420	481	542	601	660	721	843	964
4.0	202	252	302	353	403	454	504	554	605	707	808
5.0	172	214	257	300	342	385	428	471	513	601	687
6.0	144	180	216	252	288	324	361	396	432	505	577
7.0	122	153	184	214	245	276	306	337	367	428	489
8.0	104	130	156	182	208	234	260	286	312	364	415
9.0	88	110	132	154	175	197	219	241	263	307	351
10.0	73	92	110	128	147	165	183	202	220	257	293

Table A-3.—Average distance (feet) between residual trees in relation to average diameter (inches d.b.h.) and growing stock level

Ave. stand d.b.h. after thinning	Growing stock level										
	40	50	60	70	80	90	100	110	120	140	160
2.0	12.5	11.1	10.2	9.4	8.8	8.3	7.8	7.5	7.2	6.7	6.3
3.0	13.4	12.0	11.0	10.2	9.5	9.0	8.5	8.1	7.8	7.2	6.7
4.0	14.7	13.2	12.0	11.1	10.4	9.8	9.3	8.9	8.5	7.9	7.3
5.0	15.9	14.4	13.0	12.0	11.3	10.6	10.1	9.6	9.2	8.5	8.0
6.0	17.4	15.6	14.4	13.2	12.3	11.6	11.0	10.5	10.0	9.3	8.7
7.0	18.9	16.9	15.4	14.3	13.3	12.6	11.9	11.4	10.9	10.1	9.4
8.0	20.5	18.3	16.7	15.5	14.5	13.6	13.0	12.3	11.8	10.9	10.2
9.0	22.3	20.1	18.2	16.8	15.8	14.9	14.1	13.4	12.9	11.9	11.1
10.0	24.4	21.8	20.1	18.4	17.2	16.2	15.4	14.7	14.1	13.0	12.2

Alexander, Robert R., and Carleton B. Edminster. 1981. Management of ponderosa pine in even-aged stands in the Black Hills. USDA Forest Service Research Paper RM-228, 10p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Potential production of ponderosa pine in the Black Hills is simulated for various combinations of stand density, site index, age, and thinning schedule. Such estimates are needed to project future development of stands managed in different ways for various uses.

Keywords: Stand growth, stand yield, forest management, *Pinus ponderosa*, Black Hills

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Rocky Mountains

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Research Paper
RM-229

Management of Lodgepole Pine in Even-Aged Stands in the Central Rocky Mountains

Robert R. Alexander
Carleton B. Edminster

Foreword

This publication is intended to supplement the authors' article "Lodgepole pine management in the central Rocky Mountains," Journal of Forestry 78(4):196-201. Included are graphical, tabular, and descriptive information that could not be included in the Journal of Forestry, but are useful to land managers.

—Robert R. Alexander

Abstract

Potential production of lodgepole pine in the central Rocky Mountains is simulated for various combinations of stand density, site quality, ages, and thinning schedules. Such estimates are needed to project future development of stands managed in different ways for various uses.

Cover Photo:—Second-growth lodgepole pine on site index 80 lands thinned to a GSL of 80, Fraser Experimental Forest, Colorado. Stand was about 60 years old when thinned in 1976.

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Robert R. Alexander and Carleton B. Edminster

Silviculture of Lodgepole Pine in the Central Rocky Mountains

Lodgepole pine (*Pinus contorta* Dougl. ex Loud) is the second largest timber resource in the central Rocky Mountains in volume and area of commercial forest (Choate 1963, Miller and Choate 1964). It reaches maximum development in the subalpine forest zone, on south and west slopes, at elevations between 8,500 and 10,500 feet.

Lodgepole pine forests have yielded a wide variety of timber products and forage for livestock and big game, but other resources are now becoming increasingly important. How these forests are handled affects all uses. For example, if timber volume is the primary objective, growing stock level[2] (GSL) should be maintained at 120 to 160. Forage production and water yield are substantially increased only at much lower GSL's. Low to medium GSL's generally are considered necessary to improve recreational opportunities and enhance esthetics. Wildlife habitat varies from uncut to open forests. Improvement of middleground and background esthetics generally requires a combination of open, low stocking, and high stocking levels that provide contrasts.

Although land managers must increasingly direct their practices toward multiple use, these practices must be based on sound silvicultural principles. Moreover, land managers must understand the tradeoffs between the timber resource and other physical, social, and economic considerations.

Clearcutting old-growth stands and allowing cutover areas to regenerate naturally, regardless of the time required or the stocking achieved, was a common practice for many years. Today, increased management intensity requires (1) prompt replacement of the old stand with a new stand, (2) increasing growth of the new stand by control of stand density, and (3) increasing yields by periodic thinning to maintain stocking control and growth rates.

In old-growth, unmanaged stands, average annual growth is only about 25 to 40 fbm per acre, mainly because of the large number of small trees and the high incidence of dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engel.). Under even-aged management, annual net growth can be increased to 150 to 400 fbm per acre by controlling stand density and reducing dwarf mistletoe infection (Edminster 1978).

Stand density control offers the greatest opportunity for increasing wood production by increasing growth rates and reducing mortality, but harvested stands must be replaced promptly to minimize the time required to reach maximum yields. Low stumpage values have also hindered intensive management in the central Rocky Mountains. Improving stumpage values will allow the forest manager to do the cultural work needed to increase timber production.

Establishment of Regeneration

Lodgepole pine is best maintained as a vigorous, productive forest under an even-aged management system. While clearcutting is the most common method of converting old growth to managed stands, the standard shelterwood system also can be used where wind and pest problems permit, or where regeneration requirements or management objectives are best met by maintaining continuous cover. Uneven-aged systems generally are not effective in ensuring natural regeneration or increasing growth of the replacement stand.

Entire stands, blocks, patches, or strips can be clearcut or shelterwood cut. Clearcutting can be readily adapted to multiple-use land management by judicious selection of size, shape, and arrangement of openings, in combinations with other high-forest cutting practices. With a clearcut option, the size of opening that is likely to receive sufficient seed to restock receptive seedbeds is influenced by whether the seed is dispersed by open or closed cones. It can not be assumed that the cone habit is either serotinous or nonserotinous. Each stand must be examined and classified as closed cone, open cone, or intermediate. If the stand is

[2]Growing stock level (GSL) is defined as the residual square feet of basal area when average stand diameter is 10 inches d.b.h. or more. Basal area retained in a stand with an average diameter of less than 10 inches is less than the designated level (Myers 1971, Edminster 1978). Tables A-1, A-2, and A-3 in the appendix give the basal area, number of trees, and square spacing in stand with average diameters after thinning of 2 to 10 inches, for GSL levels 40 to 160.

classified as closed cone, it then must be determined if sufficient sound seed is stored in closed cones to provide an adequate seed source for natural regeneration.

Clearcutting stands with serotinous cone habit.—Clearcuts of various sizes and shapes will restock if there is enough seed. However, there is only one opportunity for natural regeneration, because the seed supply is in the slash-borne cones. There is no advantage to cutting openings larger than 30 to 40 acres, even for dwarf mistletoe control, and openings of 10 to 20 acres would be more compatible with other uses. On south slopes and other difficult regeneration chances, it may be desirable to cut openings smaller than 10 acres to provide a supplemental seed source in trees standing around the perimeter.

Clearcutting stands with nonserotinous or intermediate cone habit.—The cutting unit must be designed so that seed from the surrounding timber margin reaches all parts of the opening, unless artificial regeneration is planned. Effective seed dispersal distance from standing lodgepole pine has not been studied in the central Rocky Mountains, but studies elsewhere (Boe 1956, Dahms 1963, Tackle 1964) indicate that, with favorable seedbed and environmental conditions, the effective seeding distance in lodgepole pine is about 150 feet. The maximum width of opening likely to restock to natural reproduction is, therefore, 300 feet, or about four to five times tree height. Further, it is not likely only one seed crop will provide enough seedfall for adequate stocking. On south slopes, openings should be smaller—150 feet wide, or about two to three times tree height. If larger openings are cut, the area beyond effective seeding distance must be planted.

If a shelterwood option is used, seed for regeneration is dispersed from trees left standing on the area after the seed cut (nonserotinous cones), or dispersed from cones attached to logging slash or knocked loose on the ground (serotinous cones) after the seed cut. Logging damage to established regeneration must be controlled by (1) locating and marking skid roads on the ground at about 200-foot intervals, and confining skidding equipment to these skid roads to reduce indiscriminate travel over the cutover area; (2) felling trees in a herringbone pattern to the skid road to reduce disturbance when logs are moved onto the skid road; and (3) close coordination between felling and skidding operations, especially in stands with large volumes, where it is necessary to fell and skid one tree before another is felled (Alexander 1974).

Regeneration may be slow to establish and seedlings poorly distributed, regardless of cutting method or cone habit, if seed supply is inadequate (viable seed in closed cones is often destroyed during slash treatment), seedbeds unfavorable, or environmental conditions adverse after seed dispersion. If cutover stands are not adequately stocked within 5 years after the final harvest, the manager must take action under the regulations of the National Forest Management Act of 1976 to artificially regenerate the areas.

With any of the even-aged systems, the minimum initial stocking recommended is 1,200 to 1,500 stems per acre at age 10 years (Alexander 1974). This density ensures that at least 1,000 stems per acre will survive to age 30 years, without reduction in height or diameter growth (Alexander 1960).

Need for Early Precommercial Thinning

Establishing a new stand is only the beginning. Trees must have room to grow to reach merchantable size in a reasonable time. Where lodgepole pine has regenerated after clearcutting, stands are often overstocked. For example, with 4,000 to 5,000 stems per acre, the trees will reach an average diameter of about 2 inches d.b.h. in 30 years, and one-fourth of the 120-year rotation will have been passed (Alexander 1965). For acceptable growth rates, stands must be thinned to 1,200 to 1,500 stems per acre during the first 10 years.

Although enough well-distributed seedlings have been established within 5 years using the shelterwood system, growth is retarded if the overwood is not promptly removed. In stands infested with dwarf mistletoe, the longer the overwood remains in place, the greater the probability of transmitting the disease to the new stand (Alexander 1975).

Estimates of Growth Under Intensive Management

Intensive management provides many opportunities for increasing usable wood production, but estimates of stand development under various management regimes are needed.

The best information on lodgepole pine growth from sapling stage to final harvest, under even-aged management, with either a clearcut or shelterwood cut, is provided by field and computer simulation procedures developed by Myers (1971) and Myers et al. (1971) and refined by Edminster (1978). The procedures were developed from field data on past growth related to stand density, age, and site quality. Data were obtained from a large number of permanent and temporary plots in thinned stands throughout the central Rocky Mountains.

The modeling concept used in these programs regards the whole stand as the primary model unit characterized by average values. The equations upon which the growth and yield simulations are based are given in the program listing in the appendix of Myers et al. (1971). The programs project stand development by consecutive, 10-year periods, and include relationships to project average stand diameter, average dominant and codominant height, and number of trees per acre for stands not infested by dwarf mistletoe. Separate relationships express effects of dwarf mistletoe and changes in the intensity of infestation. Average diameter at the end of a projection period is a function of average diameter at the beginning of the period, site index, and basal area per acre. Periodic average dominant and codominant height growth at managed stand densities is a function of age and site index. Periodic mortality is a function of average diameter and basal area per acre. Stand volume equations are used to compute total cubic feet per acre; factors are computed to convert to merchantable cubic feet and board feet. Prediction equations are included to estimate the effects of differing intensities of thinning from below and above on average diameter, average dominant and codominant height, and trees retained per acre.

Yield simulations discussed in the following paragraphs were made from the same hypothetical initial stand conditions for all growth parameters:

1. Average total age at first thinning is 30 years
2. Average stand diameter is 4.5 inches d.b.h.[3]
3. Stand density is 1,000 trees per acre
4. Site index is 50-, 60-, 70- and 80-foot classes, at base age 100 years (Alexander 1966)
5. Dwarf mistletoe rating is 0 (Hawksworth 1977)
6. Projections were made for 50 years (stand age 80) and 90 years (stand age 120)
7. Thinnings from below were made every 10, 20, and 30 years to GSL's of 40, 60, 80, 100, 120, 140 and 160, with initial and subsequent entries made to the same GSL
8. A clearcut option was used
9. Minimum size for inclusion in board-foot volume determinations was 6.5 inches d.b.h. to a 6-inch top
10. All thinnings were made as scheduled, even though all could be precommercial.

Diameter Growth

Periodic mean annual diameter growth of lodgepole pine is related to stand density and site quality, but is affected little by the cutting cycles tested. Cutting cycles do influence average stand diameter, however, because thinning from below increases average diameter at each entry. Actual basal area in a stand with an average diameter of less than 10 inches d.b.h. continues to increase, because periodic thinning does not reduce basal area to a fixed (GSL) amount until an average stand diameter of 10 inches d.b.h. is reached. Consequently, the rate of diameter growth for a given GSL is not constant over time and is essentially a negative exponential function of basal area per acre in the program. In contrast, periodic diameter growth is a linear function of site index, so that differences in diameter growth resulting from site quality are constant throughout the range of GSL's and rotations examined.

Growth rates and changes in diameter resulting from thinning frequency were examined to determine average size of trees relative to rotation age, site index, and stand density. For example, with a 20-year cutting cycle, trees reach average stand diameters of 7.9 to 15.3 inches d.b.h. after 80 years, and 10.1 to 24.1 inches d.b.h. after 120 years, for the range of GSL's and site indexes tested (table 1). On an average site (index 60), with a 20-year cutting cycle, trees reach 10 inches d.b.h. at 56 to 100 years of age for the GSL range of 40 to 160 (fig. 1).

[3]*Average stand diameter is the diameter of the tree of average basal area; it is not the average of all the tree diameters.*

Height Growth

Periodic mean annual height growth of lodgepole pine increases with site index and decreases with age, but is influenced little by GSL's, or the cutting cycle. However, since fewer and, therefore, taller trees are left after each thinning from below, the mean height of the dominant and codominant trees is increased slightly at each entry. The increase is positively correlated with thinning frequency and negatively correlated with GSL.

Basal Area Growth

Periodic mean annual basal area increment is related to stand density, site quality, and frequency of thinning. Because actual basal area after thinning continues to increase in a stand until average stand diameter reaches 10 inches d.b.h. and thinning reduces basal area to a fixed amount (GSL), the rate of basal area growth for a given GSL is not constant over time. Periodic basal area increment is greater at higher GSL's, but the rate of increase diminishes at the higher stand densities. Periodic mean basal area growth is also greater at higher site indexes. Moreover, the dif-

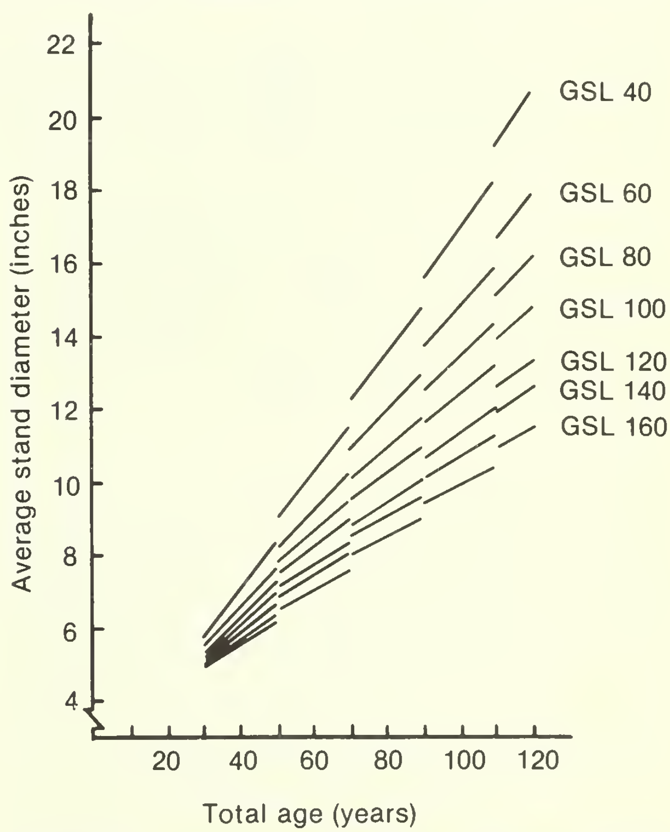


Figure 1.—Estimated average stand diameter in relation to age and growing stock level on site index 60 lands with a 20-year reentry schedule.

Table 1.—Estimated average stand diameter (inches) and number of trees per acre of lodgepole pine at final harvest in relation to growing stock levels, site quality, rotation age, and cutting cycle

		Growing stock level													
		40		60		80		100		120		140		160	
Rotation age	Cutting cycle	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees
								Site index 50							
80	10	13.2	51	11.6	96	10.7	144	9.7	214	9.0	287	8.5	364	8.1	434
120		20.9	19	18.0	39	15.9	65	14.2	101	12.6	153	11.9	197	10.7	276
80	20	12.6	56	11.0	108	10.3	157	9.4	225	8.8	296	8.2	382	7.9	449
120		19.0	23	16.1	48	14.5	78	13.1	119	11.8	175	10.9	237	10.1	309
80	30	12.0	70	10.5	126	9.8	192	9.1	266	8.5	344	7.9	427	7.6	499
120		17.2	39	14.7	76	13.2	121	12.0	176	10.9	243	10.0	320	9.2	390
								Site index 60							
80	10	14.4	43	12.8	80	11.5	131	10.8	183	10.2	240	9.4	318	8.8	393
120		23.0	16	20.1	31	17.9	52	16.3	77	15.1	108	13.5	157	12.4	208
80	20	13.5	49	12.0	93	11.0	144	10.3	199	9.5	272	9.1	334	8.5	413
120		20.7	20	17.0	39	16.1	64	14.8	95	13.3	139	12.6	181	11.5	245
80	30	12.7	71	11.4	120	10.4	179	9.8	245	9.1	322	8.7	394	8.2	473
120		18.9	33	16.3	64	14.5	104	13.5	146	12.2	207	11.4	267	10.6	327
								Site index 70							
80	10	15.2	39	13.7	72	12.5	113	11.7	160	10.9	216	10.4	276	9.9	338
120		24.8	14	22.0	26	19.7	43	18.2	63	16.7	89	15.7	117	14.6	154
80	20	14.2	45	12.8	82	11.8	128	11.0	180	10.4	236	10.0	297	9.3	374
120		22.2	17	19.6	33	17.7	54	16.3	79	15.1	109	14.2	143	13.0	190
80	30	13.5	64	12.0	111	11.2	168	10.4	233	9.9	296	9.5	362	8.9	435
120		20.5	29	17.7	56	16.1	88	14.8	127	13.8	172	12.9	217	12.0	276
								Site index 80							
80	10	16.3	34	14.7	62	13.5	99	12.8	134	12.0	182	11.3	237	10.4	298
120		26.8	12	23.7	23	21.6	36	20.3	51	18.6	73	17.6	94	16.4	114
80	20	15.3	40	13.8	72	12.6	113	12.0	154	11.3	207	10.6	270	10.0	320
120		24.1	15	21.3	28	19.3	46	18.0	65	16.9	88	15.7	119	14.9	143
80	30	14.5	56	13.1	102	11.8	157	11.2	214	10.9	262	10.1	338	9.7	400
120		22.1	25	19.7	46	17.3	79	16.2	110	15.2	125	14.2	180	13.6	225

ferences in basal area growth between site classes become progressively greater with higher GSL's. Periodic mean basal area increment is greater with a 30-year cutting cycle than with more frequent entries at all growing stock levels examined.

Total Cubic-Foot Volume Increment

Cubic-foot volume production is related to stand density, site quality, rotation age, and frequency of thinning (table 2). Although mean annual cubic volume increment increases as GSL and site index increase, the rate of increase diminishes as GSL increases, while the differences in growth between site classes become greater (fig. 2). Cubic volume increment will apparently continue to increase slightly at GSL's above 160 when site index is 70 or greater. At GSL's higher than 120, there is no difference in total cubic-foot volume production between a 20- and a 30-year cycle (table 2). Cubic-volume growth is unrelated to length of rotation, but at GSL's up to 120 it is greater with a 30-year cutting cycle than with a shorter one (table A-4).

Board-Foot Volume Increment

Board-foot volume production is related to all stand parameters evaluated (table 3). Mean annual sawtimber volume increases throughout the range of GSL's tested on site index 70 and 80 lands, but generally levels off or declines at GSL's 140 and above on the poorer sites (fig. 3, table A-5). Board-foot volume growth increases with site quality, and the differences in growth between site classes becomes greater as GSL increases. Throughout the range of GSL's, average annual board-foot increment per acre is always greater for a given site class on a 120-year rotation than on an 80-year rotation (fig. 4).

At GSL's 40 to 100, board-foot growth is greater on a 30-year cutting cycle, but with heavier stocking, growth is greater with more frequent thinnings (fig. 5).

Maximizing Board-Foot Volume Yields

What yields can be expected with intensive management of lodgepole pine to maximize timber production?

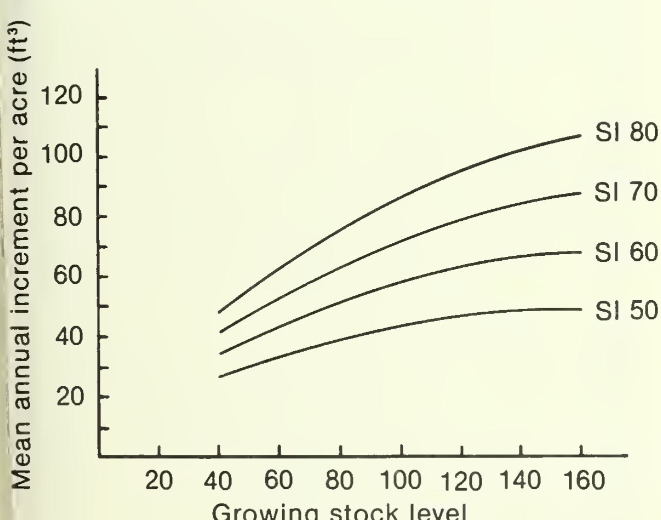
Table 2.—Estimated total cubic-foot volume production per acre of lodgepole pine in relation to growing stock levels, site quality, rotation age, and cutting cycle

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		*thousand cubic feet*						
		Site Index 50						
80	10	2.29	2.66	3.02	3.32	3.55	3.74	3.74
120		3.12	3.84	4.43	4.94	5.41	5.76	5.78
80	20	2.31	2.74	3.11	3.40	3.61	3.71	3.72
120		3.24	4.10	4.67	5.17	5.60	5.83	5.78
80	30	2.38	2.82	3.22	3.50	3.66	3.68	3.68
120		3.36	4.10	4.82	5.40	5.66	5.70	5.56
		Site Index 60						
80	10	2.87	3.41	3.96	4.42	4.82	5.13	5.20
120		3.88	4.85	5.72	6.49	7.16	7.64	7.86
80	20	2.95	3.54	4.08	4.53	4.90	5.13	5.25
120		4.12	5.17	6.10	6.90	7.54	7.93	8.11
80	30	3.08	3.70	4.30	4.78	5.08	5.20	5.28
120		4.32	5.47	6.46	7.22	7.73	7.94	7.96
		Site Index 70						
80	10	3.46	4.16	4.89	5.53	6.08	6.51	6.66
120		4.63	5.86	7.02	8.04	8.92	9.53	9.94
80	20	3.59	4.34	5.05	5.66	6.18	6.54	6.78
120		4.99	6.36	7.57	8.63	9.47	10.03	10.44
80	30	3.78	4.58	5.38	6.05	6.50	6.72	6.88
120		5.28	6.84	8.09	9.11	9.79	10.19	10.36
		Site Index 80						
80	10	4.04	4.91	5.82	6.63	7.34	7.90	8.11
120		5.39	6.86	8.32	9.59	10.66	11.41	12.01
80	20	4.23	5.14	6.02	6.78	7.47	7.98	8.30
120		5.87	7.55	9.06	10.36	11.40	12.16	12.77
80	30	4.47	5.46	6.46	7.32	7.92	8.24	8.48
120		7.44	8.21	9.72	10.99	11.86	12.43	12.76

Table 3.—Estimated board-foot volume production per acre of lodgepole pine in relation to growing stock levels, site quality, rotation age, and cutting cycle (trees 6.5 inches d.b.h. to a 6-inch top)

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		*thousand board feet*						
		Site Index 50						
80	10	6.1	7.6	9.0	9.9	10.8	11.4	11.8
120		10.6	13.4	16.1	17.9	19.3	20.6	20.8
80	20	6.0	7.6	9.2	10.4	10.7	11.0	[1]0
120		10.9	13.9	16.4	18.8	19.7	20.4	19.9
80	30	6.9	8.5	9.4	9.8	10.0	0	0
120		12.0	15.0	16.8	18.6	19.2	19.2	19.0
		Site Index 60						
80	10	7.8	10.0	12.2	13.9	15.6	16.9	17.8
120		13.6	17.6	21.5	24.5	27.1	29.0	29.8
80	20	8.2	10.4	12.6	14.4	15.5	16.6	16.8
120		14.5	18.7	22.6	25.8	28.1	29.8	30.1
80	30	9.3	11.7	13.4	14.6	15.2	15.6	15.8
120		16.2	20.4	24.0	26.4	27.6	28.2	28.6
		Site Index 70						
80	10	9.6	12.4	15.4	17.9	20.4	22.4	23.8
120		16.6	21.8	26.9	31.1	34.9	37.4	38.8
80	20	10.3	13.2	15.9	18.4	20.3	22.1	23.2
120		18.1	23.5	28.7	33.5	36.5	39.0	40.3
80	30	11.7	14.9	17.4	19.4	20.4	21.2	21.4
120		20.4	26.4	31.2	34.2	36.0	37.2	38.2
		Site Index 80						
80	10	11.4	17.4	18.6	21.9	25.2	27.9	29.8
120		19.6	26.0	32.3	37.7	42.7	45.8	47.8
80	20	12.5	16.0	19.3	22.4	25.1	27.6	29.6
120		21.7	28.3	34.8	40.8	44.9	48.2	50.5
80	30	14.1	18.1	21.4	24.2	25.6	26.8	27.0
120		24.6	32.4	38.4	42.0	44.4	46.2	47.8

[1]*Stand board-foot volume is not computed when average stand d.b.h. is less than 8.0 inches.*



igure 2.—Estimated mean annual total cubic-foot volume increment per acre in relation to growing stock level and site quality for a 120-year rotation with a 20-year reentry schedule.

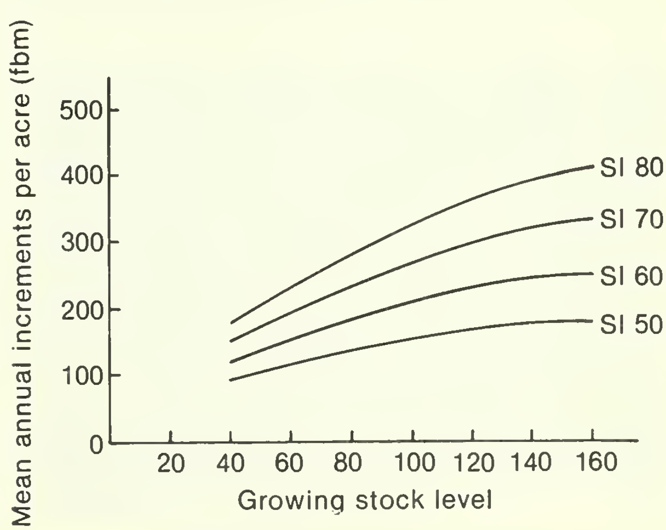


Figure 3.—Estimated mean annual board-foot volume increment per acre in relation to growing stock level and site quality for a 120-year rotation with a 20-year reentry schedule.

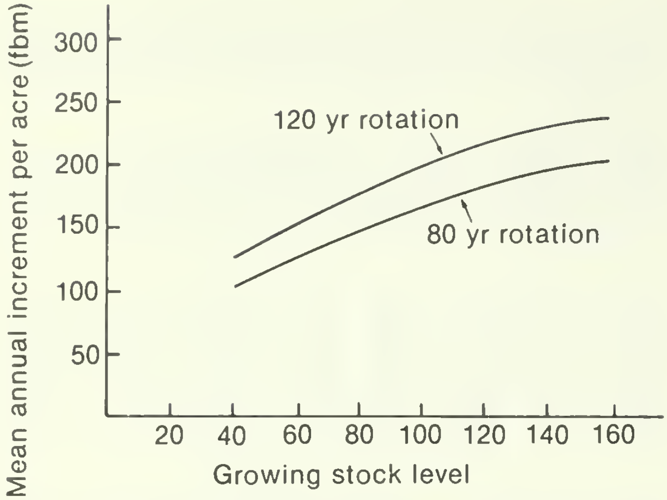


Figure 4.—Estimated mean annual board-foot increment per acre on site index 60 lands with a 20-year reentry schedule in relation to growing stock level and rotation age.

If the objective is to integrate timber production with other resource uses, what are the timber tradeoffs? How can these objectives be attained with the fewest precommercial thinnings?

Large volume production per acre, 50,500 board feet, is attained on site index 80 lands, at GSL 160, with a 120-year rotation, and a 20-year cutting cycle (table 3). These stands will contain about 140 trees per acre with an average diameter of nearly 15 inches d.b.h. at rotation age (table 1).

Volume production substantially declines when GSL is reduced. The decline is greater with each successive reduction. At site index 60 and 70, largest volume production also occurs at GSL 160, with a 120-year rotation and a 20-year cutting cycle, but at site index 50, the greatest production is at GSL 140, with GSL's 100 and 120 nearly as favorable.

Table 3 also shows the amount of volume given up as GSL is reduced from 160 to 40 for all combinations of

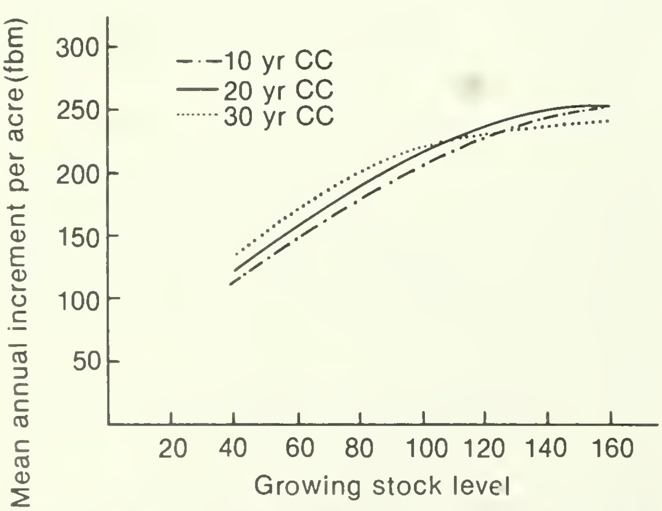


Figure 5.—Estimated mean annual board-foot increment per acre in relation to reentry schedules on site index 60 lands.

stand parameters examined. Moreover, it shows that more volume can be produced over the same time span with 120-year rotations than with 80-year rotations. For example, on-site index 80 lands, maximum board-foot volume production per acre for two 120-year rotations, or 240 years, would be 101,000 fbm, compared with 89,400 fbm on three 80-year rotations, also 240 years.

Whether the board-foot volume potentials can be achieved depends largely on how much money can be invested in thinning. It is assumed that once a stand reaches a minimum merchantable size of 6.5 inches average d.b.h. to a 6-inch top, market conditions permit intermediate thinnings to be made as scheduled. If economic constraints allow only one precommercial thinning in the life of the stand, the manager's options are severely restricted. For example, at site index 50 and 60, the stand density must be reduced to a GSL of 60, and the cutting cycle increased to 30 years (table 4). At site index 70, stand density must be reduced to a GSL of 80; and at index 80, where there is more flexibility, a GSL of 120 can be maintained with a 30-year cutting cycle (fig. 6).

Table 4.—Number of precommercial thinnings of lodgepole pine in relation to growing stock levels, site quality, rotation age, and cutting cycle

Cutting cycle	Site index	Growing stock level						
		40	60	80	100	120	140	160
years								
				Site Index 50				
80	10	2	3	3	4	4	5	5
120		2	3	3	4	4	5	5
80	20	1	2	2	2	3	3	3
120		1	2	2	2	3	3	3
80	30	1	1	2	2	2	2	3
120		1	1	2	2	2	2	3
				Site Index 60				
80	10	2	2	3	3	3	4	4
120		2	2	3	3	3	4	4
80	20	1	2	2	2	2	2	3
120		1	2	2	2	2	2	3
80	30	1	1	2	2	2	2	3
120		1	1	2	2	2	2	3
				Site Index 70				
80	10	2	2	3	3	3	3	4
120		2	2	3	3	3	3	4
80	20	1	2	2	2	2	2	2
120		1	2	2	2	2	2	2
80	30	1	1	1	2	2	2	2
120		1	1	1	2	2	2	2
				Site Index 80				
80	10	2	2	2	3	3	3	3
120		2	2	2	3	3	3	3
80	20	1	1	2	2	2	2	2
120		1	1	2	2	2	2	2
80	30	1	1	1	1	1	2	2
120		1	1	1	1	1	2	2

Figure 6.—Second-growth lodgepole pine on site index 80 lands thinned to GSL 120, Fraser Experimental Forest, Colorado. Stand was about 60 years old when thinned in 1976.

Thinnings to a constant GSL have been assumed up to this point. However, if only one precommercial thinning is possible, managers can increase their flexibility by changing GSL's with successive thinnings. For example, on site index 70 lands, with a 30-year cutting cycle, GSL may be initially reduced to 80 but increased to 100 at the second thinning, and to 120 at the third thinning. Volume production will be less than maximum, but reasonably close to that available from a stand maintained at a constant GSL 120. Attempts to raise the GSL to 120 at the time of the second entry into the stand would result in a second precommercial thinning. By following this procedure, managers can increase GSL on site index 50 and 60 lands from 60 to 100.

The manager has another option if only one precommercial thinning is possible. The initial thinning can be made on schedule and the second entry delayed until the stand reaches minimum merchantable size. This will increase the second thinning interval to 40 years or more, increase the length of the rotation, and result in less than maximum volume production.

Where economic conditions permit two precommercial thinnings, the manager has the flexibility to maximize timber production on site index 60, 70, and 80 lands. On site index 50 lands, a GSL of 100 could be maintained, or it could be increased to GSL 140 by changing levels with successive reentries.

Managers may also elect to change GSL's with successive reentries regardless of the number of precomnerical thinnings that are economically possible. With this procedure, the concern about retaining many trees early in the life of the stand, and fewer trees later in the rotation can be avoided. For example, stand density can be initially reduced to GSL's 60 to 100 and successively increased to GSL's 120 to 160, depending upon site quality and cutting cycle. Volume production will be less than if stand density were maintained at a constant and higher, initial GSL, however.

Tradeoffs to Increase Values of Other Resources

Understory vegetation in lodgepole pine forests is potentially important as forage for big game and livestock, but as overstory density increases, the productivity of the understory decreases. This relationship is generally shown to be curvilinear (Basile 1975). To increase forage, the manager must be willing to reduce timber production. For example, clearcutting old-growth stands to bring them under management increases the amount of understory (Trappe and Harris 1958, Basile and Jensen 1971, Regelin and Wallmo 1978). The changes in species composition and palatability vary considerably, depending upon habitat type. The changes in production and composition persist for 10 to 20 years before competition from tree reproduction begins to reduce understory vegetation. Thinning second-growth lodgepole pine also increases the amount and changes the composition of understory species (Dealy 1975). These changes are generally greatest in low-density stands.

Although no methods or data are available to quantify changes in understory herbage production under lodgepole pine, for the range of GSL's, site indexes, rotation ages, and cutting cycles examined here, some general conclusions can be drawn. To increase average herbage production to even moderate levels, the manager must be willing to reduce basal area stocking per acre to GSL 60 or less (fig. 7). To maintain forage production, the manager must be able to make additional cuts in the stand at intervals of at least every 20 years.

Lodgepole pine forests are important water-yielding areas in the Rocky Mountains. The proportion of water yield to precipitation is high because of the cold climate, short growing season, and the accumulation of an overwinter snowpack (Hoover 1975). Because most of the water available for streamflow comes from snowmelt, the most efficient pattern of timber harvest

Figure 7.—Second-growth lodgepole pine on site index 80 lands thinned to GSL 40, Fraser Experimental Forest, Colorado. Stand was about 60 years old when thinned in 1976.

for water yield in old-growth stands is to clearcut about 30-40% of a drainage (1) in small, irregular-shaped patches about five to eight times tree height in diameter, (2) protected from the wind, and (3) interspersed with uncut patches of about the same size (Leaf 1975). Leaf and Alexander (1975) used simulations generated by hydrologic and timber yield models (Myers et al. 1971, Leaf and Brink 1973, Edminster 1978) to estimate water available for streamflow on lands where lodgepole pine had been clearcut and the regenerated stand was being managed under various alternatives. Figure 8 shows projected water yield increases over a 120-year rotation, at GSL 100, on a 30-year cutting cycle, on site index 60 lands. Simulation also showed that estimated water yield was influenced little by any combination of initial and subsequent GSL's in managed stands that ranged from 80 to 120. More water should be available for streamflow at lower stand densities because of the reduction in consumptive use by trees, but no comparisons were made at higher or lower densities. One unknown factor is water use by competing understory vegetation associated with different habitat types for different GSL's.

Information from research and simulation makes clear that stand density must be substantially reduced to and maintained at a low GSL to benefit water and forage resources. Amenity values and recreational opportunities are generally improved only at low stocking. But considerable timber volume production is given up at low stand densities. For example, on-site index 80 lands, at GSL 60, with a 120-year rotation and a 20-year thinning schedule, yield is 28,300 fbm per acre or 22,200 fewer than the 50,500 fbm produced at GSL 160. If the GSL is reduced to 40, the loss in volume production is 28,800 fbm per acre (table 3).

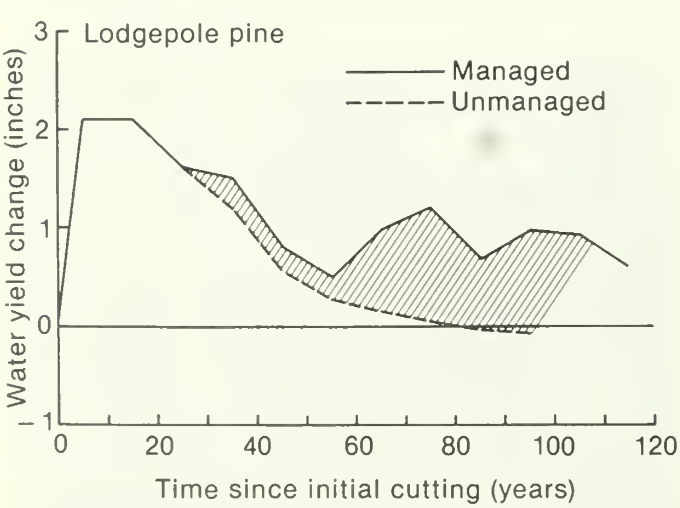


Figure 8.—Projected changes in annual water yield from simulation for GSL 100 on site index 60 lands, with a 30-year cutting cycle, and a 120-year rotation (Leaf and Alexander 1975).

Management Caution

This simulation program provides growth estimates that appear reasonable and consistent within the limits of current knowledge, but no lodgepole pine stand has been under management for a long time, and simulation extends beyond the limits of the available data base. Comparisons of estimates with actual values from plots established to provide growth information will be needed to verify simulated responses.

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Appendix

Table A-1.—Basal areas (square feet per acre) after intermediate cutting in relation to average diameter (inches) and growing stock level

Average stand d.b.h. after cutting	Growing stock level						
	40	60	80	100	120	140	160
1.0	3.0	4.5	6.0	7.5	9.0	10.5	12.0
2.0	6.0	9.1	12.1	15.1	18.2	21.2	24.2
3.0	11.8	17.8	23.7	29.6	35.6	41.5	47.4
4.0	17.6	26.4	35.2	44.0	52.8	61.6	70.4
5.0	23.4	35.1	46.8	58.5	70.2	81.9	93.6
6.0	28.3	42.4	56.6	70.8	84.9	99.0	113.2
7.0	32.7	49.0	65.4	81.8	98.1	114.4	130.8
8.0	36.2	54.4	72.5	90.6	108.8	126.9	145.0
9.0	38.8	58.1	77.5	96.9	116.2	135.6	155.0
10.0^{+}	40.0	60.0	80.0	100.0	120.0	140.0	160.0

Table A-2.—Number of residual stems per acre after intermediate cutting in relation to average diameter (inches) and growing stock level

Average stand d.b.h. after cutting	Growing stock level						
	40	60	80	100	120	140	160
1.0	553	830	1,107	1,383	1,660	1,937	2,213
2.0	277	415	553	692	830	968	1,107
3.0	241	361	482	602	723	843	964
4.0	202	303	404	505	606	707	808
5.0	172	258	343	429	515	601	687
6.0	144	216	288	361	433	505	577
7.0	122	184	245	306	367	428	489
8.0	104	156	208	260	312	364	415
9.0	88	132	175	219	263	307	351
10.0	73	110	147	183	220	257	293

Table A-3.—Average distance (feet) between residual trees after intermediate cutting in relation to average diameter (inches) and growing stock level

Average stand d.b.h. after cutting	Growing stock level						
	40	60	80	100	120	140	160
1.0	8.9	7.3	6.3	5.6	5.1	4.8	4.4
2.0	12.5	10.2	8.9	7.9	7.2	6.7	6.3
3.0	13.4	11.0	9.5	8.5	7.8	7.2	6.7
4.0	14.7	12.0	10.4	9.3	8.5	7.9	7.3
5.0	15.9	13.0	11.3	10.1	9.2	8.5	8.0
6.0	17.4	14.2	12.3	11.0	10.0	9.3	8.7
7.0	18.9	15.4	13.3	11.9	10.9	10.1	9.4
8.0	20.5	16.7	14.5	13.0	11.8	10.9	10.2
9.0	22.3	18.2	15.8	14.1	12.9	11.9	11.1
10.0	24.4	19.9	17.2	15.4	14.1	13.0	12.2

Table A-4.—Estimated mean annual total cubic-foot volume increment per acre of lodgepole pine in relation to growing stock level, site quality, rotation ages, and cutting cycle

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		cubic feet						
		Site Index 50						
80	10	28.6	33.2	37.9	41.5	44.4	46.8	46.8
120		26.0	32.0	36.9	41.2	45.1	48.0	48.2
80	20	28.9	34.2	38.9	42.5	45.1	46.4	46.5
120		27.0	33.2	38.4	43.1	46.7	48.6	48.2
80	30	29.8	35.2	40.3	43.8	45.8	46.0	46.0
120		28.0	34.2	40.2	45.0	47.2	47.5	46.3
		Site Index 60						
80	10	35.9	42.6	49.5	55.3	60.2	64.1	65.0
120		32.3	40.4	47.7	54.1	59.7	63.7	65.5
80	20	36.9	44.2	51.0	56.6	61.2	64.1	65.6
120		34.3	43.1	50.8	57.5	67.8	66.1	67.6
80	30	38.5	46.2	53.8	59.7	63.5	65.0	66.0
120		36.0	45.6	53.8	60.2	64.4	66.2	66.3
		Site Index 70						
80	10	43.2	52.0	61.1	69.1	76.0	81.4	83.2
120		38.6	48.8	58.5	67.0	74.3	79.4	82.8
80	20	44.9	54.2	63.1	70.7	77.3	81.8	84.7
120		41.6	53.0	63.1	71.9	78.9	83.6	87.0
80	30	47.2	57.2	67.3	75.6	81.2	84.0	86.0
120		44.0	57.0	67.4	75.9	81.6	84.9	86.3
		Site Index 80						
80	10	50.5	61.4	72.7	82.9	91.8	98.7	101.4
120		44.9	57.2	69.3	79.9	88.8	95.1	100.1
80	20	52.9	64.2	75.2	84.8	93.4	99.7	103.8
120		48.9	62.9	75.5	86.3	95.0	101.3	106.4
80	30	55.9	68.2	80.8	91.5	99.0	103.0	106.0
120		52.0	68.4	81.0	91.6	98.8	103.6	106.3

Table A-5.—Estimated mean annual board-foot volume increment per acre of lodgepole pine in relation to growing stock levels, site quality, rotation age, and cutting cycle (trees 6.5 inches d.b.h. to a 6-inch top)

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		board feet						
		Site Index 50						
80	10	76	95	112	124	135	142	148
120		88	112	134	149	161	172	173
80	20	75	95	115	130	134	138	0[1]
120		91	116	137	157	164	170	166
80	30	86	106	118	122	125	0	0
120		100	125	140	155	160	160	158
		Site Index 60						
80	10	98	125	152	174	195	211	223
120		113	147	179	204	226	242	248
80	20	102	130	157	180	194	207	210
120		121	156	188	215	234	248	251
80	30	116	146	168	182	190	195	198
120		135	170	200	220	230	235	238
		Site Index 70						
80	10	120	155	192	224	255	280	298
120		138	182	224	259	291	312	323
80	20	129	165	199	230	254	276	290
120		151	196	239	279	304	325	336
80	30	146	186	218	242	255	265	268
120		170	220	260	285	300	310	318
		Site Index 80						
80	10	142	185	232	274	315	349	373
120		163	217	269	314	356	382	398
80	20	156	200	241	280	314	345	370
120		181	236	290	340	374	402	421
80	30	176	226	268	302	320	335	338
120		205	270	320	350	370	385	398

[1]*Stand board-foot volume is not computed when average stand d.b.h. is less than 8.0 inches.*

Alexander, Robert R., and Carleton B. Edminster. 1981. Management of lodgepole pine in even-aged stands in the central Rocky Mountains. USDA Forest Service, Research Paper RM-229, 11 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Potential production of lodgepole pine in the central Rocky Mountains is simulated for various combinations of stand density, site quality, ages, and thinning schedules. Such estimates are needed to project future development of stands managed in different ways for various uses.

Keywords: Stand growth, stand yield, forest management, *Pinus contorta*

Agriculture—CSU, Fort Collins

Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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Productivity Equations for Forest Vegetation Treatment Projects in the Colorado Front Range

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Productivity Equations for Forest Vegetation Treatment Projects in the Colorado Front Range

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Abstract

Regression equations have been developed which relate labor and equipment hours required for various treatment methods to characteristics of the terrain, size of job, and worker efficiency. The equations can be used for other Front Range areas. This report also offers recommendations for improvement of vegetation management programs.

[1]Headquarters is in Fort Collins, in cooperation with Colorado State University.

Productivity Equations for Forest Vegetation Treatment Projects in the Colorado Front Range

Mary Lou Richardson, David R. Betters, and George R. Sampson

MANAGEMENT IMPLICATIONS

The equations and analyses presented here were designed to provide cost prediction information and identify major cost determinants of beetle-control treatments. However, the study also provides a basis for analyzing cost determinants of other insect control programs.

The equations have several applications. They can be used by a forest manager or private landowner to (1) obtain cost estimates for a particular beetle control technique before it is begun, (2) determine the program which would produce the most treated acres given a limited budget, (3) estimate the level of work possible at a given cost for tracts under certain conditions, and (4) determine whether a bid from a private contractor is realistic.

Although the prediction equations suffer the limitation of being based on a small sample, the relationships represented are statistically significant and are useful in estimating cost and time requirements of certain treatments. They also can be used to predict total hours required. Although they provide only rough estimates, they offer a much more accurate forecast of costs than was available in planning and implementing the first year of the Front Range Vegetative Management Pilot Project. Forest managers and landowners will have to decide whether to use the year 1 equations (based on first-year Pilot Project data) or year 2 equations (based on second-year Pilot Project data). This choice should reflect their situations. Start-up periods of vegetation management programs are likely to be more costly. Equations developed from year 1 data are recommended for these periods. Equations for year 2 generally would be better predictors for subsequent periods. Also, if the forest manager or landowner feels the crew is rather inexperienced, or that work on a specific job may be interrupted frequently, it may be better to use year 1 equations. A certain amount of testing on the site might be desirable before selecting the equations for a particular situation.

INTRODUCTION

The Front Range Vegetative Management Pilot Project was implemented in 1978 in response to a catastrophic and worsening epidemic of the mountain pine beetle along Colorado's Front Range. The Pilot Project's goals were fuels management, direct beetle control, timber stand improvement (TSI), and esthetic enhancement. More than 34,000 acres of public and private forest land in Boulder County (fig. 1) were chosen as the first target of this continuing management effort because of the especially severe infestation, increased forest fire danger as a result of trees killed by the insects, intense political pressure, and the fact that Boulder County includes a mix of forest land ownerships typical of the Front Range. It was hoped that successful elements of the beetle-control program could be extended to an additional 300,000 acres of Front Range forests in similar condition.

The Colorado State Forest Service (CSFS) conducted most of the field activities required by this project, coordinating its activities with the USDA Forest

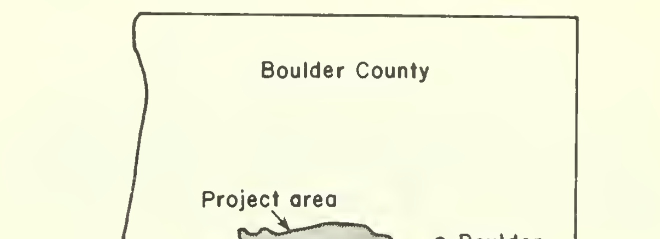

Figure 1.—Front Range Project location map.

Service (USFS), Boulder County, the City of Boulder, the Bureau of Land Management (BLM), and private organizations.

The purpose of the research reported here was to help evaluate the productivity of various treatment activities carried out in the Pilot Project and to make general recommendations regarding efficiency improvement and other program aspects.[2]

Cost analysis is an important part of any forestry program, especially one that is intended to be a continuing effort. Because actual procedures applied in Boulder County may be implemented in other locations along the Front Range, key variables affecting costs and ways to minimize expenditures must be identified. This study provides productivity guidelines that should make it possible to deal more effectively with costs when similar treatments are applied elsewhere.

The urgent nature and timing of the Pilot Project did not allow much preplanning. As a result, lack of an adequate data collection system and available records was a problem. In addition to the need for more complete data, it is important to assess all elements of the treatment processes that affect costs and, if significant, to include them in prediction models. The more variability in costs that can be accounted for through improved data collection or by addition of new variables in the model, the more precise the model will be in predicting actual treatment costs.

TREATMENT PRESCRIPTIONS

Broad management prescriptions were developed for each forest condition. These prescriptions were refined and adapted for specific stands within the Pilot Project area.

Timber Stand Improvement

Specified timber stand improvement (TSI) prescriptions called for thinning of live trees to reduce stand density in mature and overmature stands and for removing infested and dead or dying trees. The removed material was either sold or made available to the public free of charge. Where there was a market for the timber, it was sold as stumpage. Where there was no market for stumpage, but marketable products could be made from the timber removed, the timber was cut by TSI crews and sold at roadside. Revenue from these sales was used to help defray treatment costs. Standard slash disposal methods were used where it was not economically feasible to remove this material. Prediction equations were developed for TSI activities, including thinning of green trees, removal of dead and infested trees, and slash disposal. Both state-employed and contract crews were engaged in TSI activities. However, only data for state crews were adequate for use in developing the prediction equations.

Thinning

The purpose of thinning in the Pilot Project was to reduce the susceptibility of stands to mountain pine beetle attack. Few facts were known about this relationship for the Front Range. But previous observations in the Black Hills indicated that mountain pine beetle outbreaks usually develop in portions of unmanaged ponderosa pine stands with basal areas greater than 150 square feet per acre, with most trees more than 8 inches d.b.h. (Stevens et al. 1975). In the Black Hills, by thinning to maintain stand density well below 150 square feet per acre (i.e., 80 square feet per acre), bark beetle outbreaks have apparently been reduced or avoided. Even though actual proof of the effectiveness of thinning is lacking, from the Black Hills evidence it was theorized that thinning of Front Range ponderosa pine stands would result in healthier, faster growing trees less susceptible to mountain pine beetle attack. Subsequent thinnings would be necessary to maintain the stands at a density below 150 square feet per acre.

Because slash may contribute to a stand's susceptibility to attack by providing additional host wood, as well as presenting a greater fire hazard, treatment included chipping, piling and burning, or complete removal of the slash.

Infested Tree Removal

Trees in the Pilot Project infested with mountain pine beetle were felled and the beetles were destroyed by piling and burning, peeling the bark, chipping, or chemically treating infested trees after they had been felled. Generally, infested tree removal involved felling, bucking into 4-foot lengths and piling the logs into stacks varying in size from one-half cord to several cords. Some infested trees were sold for processing into commercial products. These removals were not included in this study.

Chemical Treatment

Lindane or ethylene dibromide (EDB)[3] was applied to the infested stacks of wood in an operation separate from TSI efforts. Chemicals were applied either using jerry cans which were filled with the chemical and carried to the stacks, or by a hose which was attached to a pumper truck filled with the chemical. A plastic

[2]*For a more complete description of this study, see: Mary Lou Richardson, Costs and Returns for the Front Range Vegetative Management Pilot Project. Master of Forestry Thesis. Colorado State University, Spring, 1979.*

[3]*The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.*

cover was placed over the stacks and secured by filling in trenches which were dug during the TSI operation or just before the chemical was applied.

METHODOLOGY AND RESULTS

Equations developed in regression analysis are useful for estimation. In this study, the dependent (predicted) variable is the number of hours of labor or machine time, and the independent variables include timber data, terrain, and other characteristics.

Data Collection

To develop regression equations, it was necessary to consider many variables that might influence costs. Previous attempts to identify cost determinants of standard silvicultural activities (Wikstrom and Alley 1967), as well as direct observation of the various treatment activities in the Pilot Project, provided general guidelines for determining the kind of data needed.

Data for this study were taken primarily from the records of the Colorado State Forest Service (CSFS). Foresters at the Boulder Ranger District of the Arapaho-Roosevelt National Forest, Boulder City and County foresters, and private landowners and landowner associations also were consulted.

TSI—Winter 1977-78

The first phase of the Pilot Project focused on TSI efforts in four CSFS field units, with data collection concentrated on the one for which TSI cost data were most complete. Twenty-five private ownerships with relatively complete data sets were chosen for analysis. Additional inventory information was taken on elements likely to influence cost, including total acreage treated, acreage thinned, number of beetle-infested trees cut, basal area before treatment, average diameter before treatment, basal area after thinning, average diameter after thinning, percent slope, percent rockiness, and percent of slash disposal completed.

The inventory system used was of a line-plot design, with 0.2-acre plots for a 10% sample. The sample points fell at systematic intervals designated beforehand on township maps. The system was designed to be used by one person, with line directions established by a hand compass and intervals between sample points paced. This data and the cost and inventory data provided by CSFS were the essential bases for the analysis. Two separate equations were developed—one predicting hours of labor and one predicting equipment use hours from the cost determinants involved. Hours of labor and machine time were used instead of dollar costs so that the equations could be applied even though labor and machine dollar costs changed considerably.

TSI—Autumn, 1978

Because costs for the first year of the Pilot Project probably would not be representative of costs during subsequent years, additional data were gathered during the second season of TSI activities. Inventory information deemed important, but not available, during the first year was obtained the second year.

Data available from TSI operations in the autumn of 1978 were limited because of bad weather and the increasing use of contract crews to do much of the work (cost breakdown in terms of labor hours and equipment hours was not available from contract crews). However, two CSFS units, Flagstaff and Sugarloaf, provided useful information on state crew activities during this period. An inventory was completed on the site by the unit forester, who compiled the various site characteristics requested. The following information was collected: total acreage treated, basal area before thinning (before BA), average diameter breast height after thinning (d.b.h. after), number of trees thinned per acre, number of beetle-infested trees cut, percent slope, percent rockiness, and special operational difficulties.

Chemical Treatment

An intensive program to chemically treat the stacks of infested wood that were piled during the first phase of the Project was begun in late spring of 1978. This required spraying the stacks with EDB or lindane and covering them with plastic for approximately 2 weeks. Either of two treatment methods was used, depending on the accessibility of the stacks. One method involved using a hose from a truck to drench the stacks, which were piled as close to roads as possible. The other method, for stacks that were less accessible, was for the slash crews to carry jerry cans, filled with insecticide, to the site, for application. There was greater variability in data for this method because the number of crew members involved and the amount of time spent doing this was not always recorded.

The data for chemical application were collected entirely from one unit, Sugarloaf. These data included listings of landowners whose stacks had been treated on a particular day, the number of cords and stacks treated (size of stacks varied from one-half to approximately two cords) and the names of the participating crew members. With the help of the crew boss at the site, additional data, deemed to be important for predicting costs, were developed, including the relative efficiency for each crew member, the average slope of the tracts treated on one day, and the predominant treatment method used (jerry cans or hose).

Observations for 25 treatment days were selected for the regression because their data sets were most complete, and because the characteristics of the tracts observed throughout a given day were most uniform.

For example, those days spent treating stacks located on both 0% and 40% slopes were not incorporated into the sample. (Daily slope uniformity was necessary because treatment data were only available on a daily basis). The selected data included 9 sets of data for jerry can treatment, 11 sets for hose and truck, and the rest approximately half jerry can and half truck. An attempt was made to rate, using subjective number values, the two treatment types according to their relative degree of difficulty. However, this proved unresponsive in the regression, so it became necessary to devise a separate regression for each operation type, limiting the number of observations for each regression.

Final variables chosen for regression analysis related terrain characteristics and factors of the job done to the number of cords of stacked wood treated per day and included the number of cords treated, size of stacks treated (expressed as percentage of a cord), and the size and the efficiency rating of the crew (on a scale of 1 to 10). For this rating, each crew member was judged separately and the results were compiled to give the crew a daily rating. The most obvious limitation of this rating is that individual crew members produce at varying levels of efficiency, depending on the size of the crew and other crew members with whom they are working.

TSI Prediction Equations

The original intent was to combine data sets for years 1 and 2 to produce just two regression equations—one for labor hours and one for equipment hours. However, this resulted in regression equations which systematically overestimated the time requirements for year 2, especially for moderately sized jobs. Because treatment productivity increased in the second year, it was more appropriate to develop separate regression equations for each year. Therefore, this section focuses on the development of four prediction equations which include: (1) hours of labor and equipment time as a function of site and stand characteristics on data collected during the first year of TSI activity, and (2) hours of labor and equipment time as a function of site and stand characteristics based on data collected for the second season of TSI field work. Hours of labor and equipment time include only hours actually spent on the site and exclude transportation time. Appendix 1 describes the variables included and the manner in which they were collected.

Several variables were considered (including percent basal area and percent change in average diameter at breast height caused by thinning, as well as number of acres squared) to determine whether a curvilinear model might provide a better fit for the data. Tables 1 and 2 show the important parameters of the data entered in the final runs.

The final TSI regression equations resulting from the analysis based on first year data include:

1. Hours of labor = −364.87 + 14.01 (acres treated) + 1.44 (basal area before) + 1,092.52 (percent rockiness) + 1,178.71 (percent slope) + 2.08 (basal area after).

   R^2 = 0.93; standard error of estimate = 103.05.

2. Equipment time (hours) = 173.12 + 12.38 (acres thinned) + 1.89 (basal area before) + 0.66 (number of infested trees cut) + 262.43 (percent rockiness).

   R^2 = 0.88; standard error of estimate = 67.66.

The equations based on the second year data were:

1. Hours of labor = 243.32 + 45.97 (acres treated) + 2.15 (basal area before) − 68.85 (d.b.h. before) − 0.803 (trees thinned per acre).

   R^2 = 0.90; standard error of estimate = 108.24.

2. Equipment time (hours) = 111.31 + 19.16 (acres treated) + 0.64 (basal area before) − 0.28 (trees thinned per acre) − 25.64 (d.b.h. before) + 0.17 (infested trees cut).

   R^2 = 0.88; standard error of estimate = 57.42.

Treatment times for people and machines could not be compared directly between year 1 and year 2 because of differences in treatment conditions. Generally, areas treated in year 1 had lower basal area per acre, fewer infested trees cut per acre, and fewer rock obstacles than in year 2 (tables 1 and 2). Labor and equipment hours per acre were inversely proportional to tract size during the first year of the Pilot Project. This pattern can be explained, in part, by

Table 1.—Variables included in regression equations for hours of labor and equipment hours for timber stand improvement, year 1

Variable	Mean	Range
Total hours of labor	451.29	25-1084
Acres treated	16.42	2.3-41
Acres thinned	11.77	0-31
Infested trees cut	61.86	23-115
Slope	0.18	0.05-0.35
Rockiness	0.15	0.10-0.40
Basal area before	81.88	41-212
Basal area after	46.76	3-108
Equipment hours	207.62	10-556
D.b.h. before	10.30	7.7-12.6

Table 2.—Variables included in the regression equations for hours of labor and equipment hours, year 2

Variable	Mean	Range
Hours of labor	249.71	6-1148
Acres treated	7.33	1.5-25
D.b.h. before	6.69	4-8.5
Basal area before	118.57	40-190
Trees thinned/acre	155.76	30-350
Slope	0.17	0-0.30
Infested trees cut	82.24	0-615
Equipment hours	127.21	4-498

the presence of excess workers and equipment on smaller acreages. The extent of the work to be done was often overestimated (particularly in areas of high basal area, slope, etc.) resulting in crews and equipment frequently remaining idle. It is likely that jobs on larger acreages made more efficient use of people and machines. This condition does not appear during the second operating year, where hours per acre are greatest when tract size is large. This may be caused by the longer walking distances required to get to the work area. In general, hours per acre during the second year do not have as wide a range as those for the first year (i.e., changes in plot size and conditions of the terrain do not have as substantial an effect on labor and equipment hours per acre).

Year 1, on the average, required more hours than year 2 to complete similar work, which is typical for the start-up year of a program. Forest managers need time to learn to assess adequately the needs of an area and how best to balance labor and equipment time. Inexperienced crews are more affected by terrain characteristics, such as slope and rockiness, than experienced crews. This is indicated in the regressions for year 1 where, in addition to basal area and the size of the treated tract, slope and rockiness were important productivity determinants.

In effect, year 2 shows that hours to treat are being controlled better than during year 1. Slope and rockiness no longer have the effect they did during the first year, and are replaced increasingly by characteristics of the job to be done, such as number of trees to be cut per acre in the thinning operation, and number of infested trees cut and stacked. This may be the result of crews becoming more experienced over time.

There are some important cost determinants of the Pilot Project that were not assessed through the regression analysis. Crew experience, and the wide range of ouput levels from one crew member to the next, affect costs considerably particularly in the Pilot Project, where crew members were hired hurriedly and the emphasis at the start was on numbers of workers, rather than quality of their output. This led to a large turnover of crew members during the first year; however, improved hiring and screening procedures resulted in solid, reliable crews by the second operating year. Results showed that crew turnover, and the inefficiency of particular crew members, greatly affects the variability in the total labor and equipment time required to complete a job. In addition to crew variability, unrecorded delays, such as vehicle breakdowns or malfunctioning equipment, affect the time required to complete a job. Until such factors are assessed more accurately, substantial variability will remain unaccounted for in regression analyses.

Chemical Treatment Equations

The chemical treatment regression analysis was completed by separating the data into two groups: (1) treatment by crews using jerry cans, and (2) treatment using a truck and hose. Appendix 2 defines the variables included. As a result of subdividing the chemical data treatment into these two classes, neither regression had the support of many observations, and the jerry can chemical treatment regression proved to be insignificant. Therefore, this section reports only on the regression developed for the hose and truck treatment, and refers to the jerry can treatment only for general comparison of the two methods.

The regression of truck and hose produced the following prediction equation:

> Number of cords treatable per day using truck and hose = 52.40 + 9.43 (size of stacks) + 2.32 (size of crew) − 6.14 (crew efficiency).
>
> R^2 = 0.82 standard deviation of the regression line = 3.35.

This equation can be used in the field to calculate how many cords could be treated in an 8-hour day, given particular circumstances of stack size, number of crew members, etc. As an example, 18.78 cords could be treated in an 8-hour day when the stacks were one-half cord in size, and 2 crew members with an efficiency rating of 7 were used. At $3.50 per hour for each crew member, the labor cost for treating would be $56.00 per day or $2.93 per cord. Not included in this estimate are the costs per cord of the chemical and plastic. It is assumed here that stacks to be treated by truck and hose are readily accessible by truck.

It is difficult to explain the negative coefficient of crew efficiency. It is not reasonable that more highly rated crew members would require a longer time to do work of equal quality. Since there was no measure of work quality, it is possible that the more highly rated crews were doing a more thorough job and, therefore, taking more time.

It seems extremely important that anyone working with the chemical be assigned to it willingly. Willingness to work is quite variable, and it was very difficult in the chemical treatment process to control the level of output without direct and constant supervision of the employees. The size of the crew is somewhat important. The most efficient crew size for this job is two workers, because drenching stacks and covering them with plastic is basically a two-person job. Because a knowledgeable person is likely to handle the chemical more responsibly, better performance was obtained during the second year when treatment was begun in May after forestry undergraduate students were available for summer work.

Terrain features, such as slope, clearly influence the amount of time required to carry cans to a site. Other obstacles include down trees, deep snow, and thick slash left from TSI activities. Piling stacks of wood as close to accessible roads as possible helps eliminate time-consuming walks during the chemical operation. It is important to stack the wood away from rocky soils and other impediments to reduce the amount of time spent digging trenchs around the stacks. Observations by crew bosses on the sites indicate that it may be more efficient for slash crews to dig the trenches after making the stacks rather than have chemical crews both dig and treat. Possibilities for improving efficiency in these activities warrant further attention and analysis.

The number of stacks treated per day using truck and hose was highly correlated to the size of the stacks because driving time will be much greater if the stacks are small and spread over large areas. Optimal stack size has been estimated to be approximately 4 cords, because larger sizes require an unwieldy amount of plastic. Chemical treatment work is subject to potential unplanned costs similar to those that affect TSI operations, such as equipment breakdowns and associated maintenance time. But since these events were generally not recorded or quantified for either treatment, it is difficult to evaluate their impact.

Range and Limitations

The regression equations in this study should be used only over the range of data collected in the sample, with the additional caution that predictions are more accurate in the middle range of each independent variable. Use of the equations outside of these ranges results in the possibility of very large errors. As the values of the independent variables deviate from the means, the regression confidence interval becomes larger. The relevant ranges for the variables for each of the equations are shown by tables 1, 2, 3, and 4.

Table 3.—Variables in the regression equation to predict chemical treatment capability per day by truck

Variable	Mean	Range
Cords treated per day	20.06	13.5-31.25
Size of stack	1.03	0.56-1.64
Crew size	2.54	1-4
Slope	0.24	0.20-0.40
Crew efficiency	7.82	7-8.5

Table 4.—Variables in the regression equation to predict chemical treatment capability per day by jerry cans

Variable	Mean	Range
Cords treated per day	25.26	12-53.5
Size of stack	1.07	0.81-1.40
Crew size	3.0	2-4
Slope	0.34	0.20-0.40
Crew efficiency	7.70	6.6-8.5

ADDITIONAL FACTORS

Labor

Contract defaults were a problem in the Pilot Project. The additional cost and effort required to cope with them pointed up the need to analyze bids and bidders carefully. The regression equations presented can be used to predict the total hours required to treat a particular tract and, thus, enable the forest manager to determine more accurately whether a bid from a contractor is realistic.

Planning and Coordination

It is important that management plans be based on fact—actual conditions and needs of a forest, not tentative evaluations—to avoid changes in expectations and/or costs. The degree to which management prescriptions and other plans can be formulated depends upon the likelihood and level of future funding for a designated area. Although waiting for funding before beginning the planning stage can cause the loss of valuable field time once money is available, it is often considered too risky to allocate money to planning before funds are assured.

Also considered important to the success of vegetation management programs is coordinating tasks to avoid unnecessary duplication or overlap. For instance, in the Pilot Project some unit foresters complained that excess time was spent in locating areas that could have been better identified and mapped on early visits to that site by inventory or marking crews. Further, the more completely slash is disposed of during the TSI operation, the easier and less time-consuming it is for chemical treatment crews to move around in the woods treating infested stacks. If all tasks requiring similar effort and equipment are completed during one phase of the operation, costs can usually be reduced.

Generating Revenues

As noted earlier, revenues generated from sale of removed timber can be used to help offset treatment costs. Future vegetation management programs along the Front Range may need to rely more heavily upon the generation of revenues. The CSFS considered the revenue-generating phase of the Pilot Project to be successful. Despite the fact that stumpage purchasers got a late start in harvesting, the winter of 1977-78 was especially mild and did not hinder harvesting. Markets for lumber products were especially strong along the Front Range during this period.

It would be of great benefit to future mountain pine beetle control projects if salable products could be developed from the huge volumes of residues now left on the forest floor after a conventional harvest. Much of this wood is now wasted, and even worse, it contributes to the fire hazard. Because it has not been economical to remove most of this material, it has been burned in place. Possible new products from this waste include alcohol, charcoal, or chips pressed into pellets for fuel use. If harvesting and processing of slash material into products were properly timed, most of the chemical treatment of slash could be eliminated. Since the completion of this Pilot Project and particularly during the autumn of 1979, the demand for and prices of firewood have increased tremendously in the Front Range area (Hostetler 1980). This increased demand for firewood makes vegetation management more appealing and more feasible. Sale of firewood can provide a means for removing some of the material that needs to be taken out and also provides the owner with funds to finance other activity, such as chemical treatment.

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Pesticide Precautionary Statement

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some states have restrictions on the use of certain pesticides. Check your state and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or state extension specialist to be sure the intended use is still registered.

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

APPENDIX 1.—DEFINITION OF TSI VARIABLES

Total hours of labor.—Hours spent by crews thinning, cutting, and stacking infested trees, and disposing of slash, through burning, lopping and scattering, or chipping.

Total equipment time.—Total operating hours for equipment on the site, such as chainsaws or chipper.

Acres treated.—Total acreage on which green trees were thinned and infested trees cut, stacked, and chemically treated.

Acres thinned.—Total acreage on which stands thinned to prescribed basal area. No infested trees cut.

Slope.—Percentage slope (expressed as decimal) measured by a clinometer or Abney level.

Rockiness.—Subjective evaluation of percentage of ground covered by rocky outcroppings or boulders.

Basal area before treatment.—Basal area of stand before treatment in square feet per acre as determined with an angle gage device.

Basal area after treatment.—Basal area of stand after treatment.

D.B.H. before treatment.—Average diameter breast height in inches before treatment.

Trees thinned/acre.—Number of uninfested trees thinned on each acre.

Infested trees cut.—Number of infested trees cut and stacked per tract.

APPENDIX 2.—DEFINITION OF CHEMICAL TREATMENT VARIABLES.

Cords treated/day.—Number of cords treated in an 8-hour day using different treatment methods.

Size of stack.—Average size of stacks treated in an 8-hour day, expressed as a percentage of a cord.

Crew size.—Number of workers on a crew; slash crew workers who placed cans at the site for chemical crews were counted as half-time workers.

Slope.—Average slope of tracts treated in a 1-day period, estimated by crew boss on the site.

Crew efficiency.—Each crew member was given a subjective rating by the crew boss on a scale of 1-10, 1 being the lowest. Based on these ratings, the crew was assigned a weighted rating.

Richardson, May Lou, David R. Betters, and George R. Sampson. 1981. Productivity equations for forest vegetation treatment projects in the Front Range. USDA Forest Service Research Paper RM-230, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Regression equations are presented for various forest vegetation treatment methods that relate labor and equipment time to terrain, area treated, and crew efficiency. Equations are applicable to most Front Range areas. Recommendations are made for improving productivity in vegetation management projects, particularly those required for insect control.

Keywords: Vegetation management, insect control, *Dendroctonus ponderosae*, silviculture

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

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Bottineau, North Dakota
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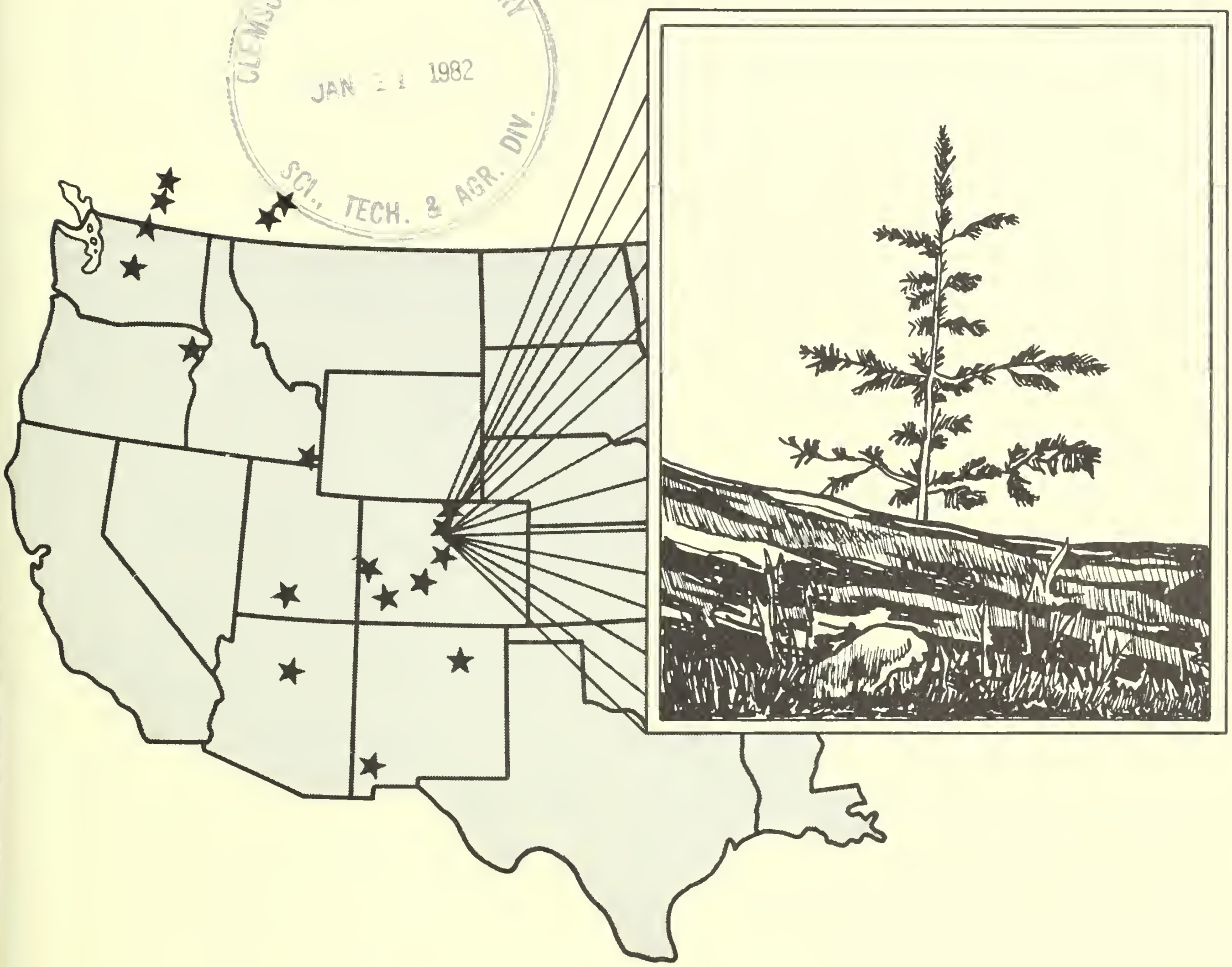
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Lubbock, Texas
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

An Engelmann Spruce Seed Source Study in the Central Rockies

Wayne D. Shepperd, Richard M. Jeffers, and Frank Ronco, Jr.



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An Engelmann Spruce Seed Source Study in the Central Rockies

by Wayne D. Shepperd, Richard M. Jeffers, and Frank Ronco, Jr.[1]
USDA Forest Service

Shepperd, Wayne D., Richard M. Jeffers, and Frank Ronco, Jr. 1981. An Engelmann spruce seed source study in the central Rockies. USDA Forest Service Research Paper RM-231, 5 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Planted Englemann spruce seedlings from 20 sources throughout North America were field tested in the central Rockies at 9,600 feet (2,930 m) elevation. Overall survival was 73% after 10 years. Significant differences in height were evident among several sources. Sources from northern latitudes and lower elevations grew best. The results demonstrate that Englemann spruce planted at high elevations can survive when proper planting techniques and yearly maintenance procedures are used.

Keywords: Genetics, *Picea engelmannii*, provenance testing, seedling growth, regeneration

[1]Shepperd and Ronco are Silviculturist and Principal Silviculturist, respectively, at the Rocky Mountain Forest and Range Experiment Station. Station headquarters is in Fort Collins, in cooperation with Colorado State University; Ronco is at the Station's Research Work Unit in Flagstaff, in cooperation with Northern Arizona University. Jeffers is Regional Geneticist with the Forest Service's Rocky Mountain Region, headquartered in Lakewood, Colo.

An Engelmann Spruce Seed Source Study in the Central Rockies

Wayne D. Shepperd, Richard M. Jeffers, and Frank Ronco, Jr.

Management Implications

Although the results of this study showed that Engelmann spruce seedlings from sources in more northerly latitudes and lower elevations grew better than those from other sources when planted in central Colorado, using seed from any source other than that of local seed zones is not recommended. Long-term studies are needed to determine the performance of seed from nonlocal sources. This study demonstrated, however, that proper planting techniques and follow-up operations can result in successful regeneration of Engelmann spruce in the central Rockies.

Introduction

Engelmann spruce (*Picea engelmannii* Parry) is widely distributed from Arizona and New Mexico to Alberta and British Columbia. Its habitat is characteristically cold and humid. The species grows at elevations ranging from about 1,960 feet (600 m), in the northern part of its range, to timberline, at over 11,800 feet (3,600 m), in the central and southern Rocky Mountains (Fowells 1965). It occurs on a wide variety of soils but grows best on moderately deep, well-drained silt and clay loam soils developed from basalt, andesite, rhyolite, shale, and limestone.

In British Columbia, southwestern Alberta, and northwestern Montana, the range of Engelmann spruce overlaps that of white spruce (*P. glauca* (Moench) Voss). In the areas of overlap, white spruce typically grows at low elevations and Engelmann at high elevations, while at intermediate elevations these two species hybridize naturally, particularly on cool, moist sites. Hybridization followed by backcrossing and natural selection within the hybrid swarms has resulted in populations with intermediate physiological and morphological characteristics (Daubenmire 1974).

With its wide geographical and elevational distribution, ability to grow on a wide range of soils, and natural hybridization with white spruce, a considerable amount of genetic variation can be expected in Engelmann spruce. Except for studies designed to evaluate genetic variation in British Columbia and western Alberta, and in the northern Rockies, little is currently known about genetic variation over the entire range of the species.

Results reported here are from the sole surviving field plantation of a nationwide Engelmann spruce seed source study, established in the late 1960's by the USDA Forest Service, North Central Forest Experiment Station. The purpose of the original study was to determine the nature and range of genetic variation in Engelmann spruce. The current study was a cooperative effort between the North Central Forest Experiment Station, the Rocky Mountain Forest and Range Experiment Station, and the Rocky Mountain Region 2, USDA Forest Service. The objective was to determine the adaptability of nonlocal seed sources to a central Rocky Mountains site.

The plantation, located near Vail, Colo., is typical of the subalpine environment, characterized by a 3-month growing season subject to climatic extremes, where both high surface temperatures and frost can be expected anytime (Alexander 1974, Noble and Alexander 1977). In addition, light intensities at these elevations can be damaging to young, unprotected spruce seedlings (Ronco 1970).

Successful regeneration of burns and large clearcut blocks has been a problem in the central Rockies for some time. Some sites have been planted several times without success. Long-range survival and growth records of Engelmann spruce plantations do not exist in the literature. This established plantation provided a unique opportunity to evaluate a number of seed sources, over a long period of time, in an extremely harsh environment.

Methods and Materials

Seed was collected between 1959 and 1964, from 20 stands of Engelmann spruce in British Columbia and the United States (table 1), by personnel of the British Columbia Forest Service, and the USDA Forest Service. The North Central Forest Experiment Station provided transplants (2:3 stock) produced at the Hugo Sauer State Nursery, Rhinelander, Wisc.

Stock was planted during June 1970, in the Moniger Creek area of the Holy Cross Ranger District, White River National Forest. The plantation was at 9,600 feet (2,930 m) elevation, on a nearly flat slope, with a northeastern aspect. The site was originally occupied by a mature Engelmann spruce—subalpine-fir (*Abies lasiocarpa* (Hook.) Nutt.) forest, containing occasional lodgepole pine (*Pinus contorta* Dougl.). Because of recent logging and a subsequent fire, no vegetation existed on the site at the time of planting. Soils are shallow, poorly developed, and quite rocky. Annual precipitation averages 30 inches (76 cm), most of which falls as snow.

Trees were planted in a randomized, complete block design, with 4-tree linear plots and 12 replications. Each planting spot was staked and labeled with seed source, block, and subsample to facilitate relocation of test trees. To provide protection against high light intensity, all trees were planted in the shade of stumps and logs, or shade was provided using suitable natural material (Ronco 1972). Spacing was irregular because

Table 1.—Origins, survival, and height growth of Engelmann spruce seed sources

Seed source	State or province	Location	Latitude	Elevation	Survival after 10 years	Total height after 10 years	Height growth 5-10 years
			° N	feet	percent	inches	inches
3231	BC	Kidd Creek	49	4,700	67	[1]47.6	24.8
3232	BC	Inlet Creek	50	4,600	70	44.5	20.9
3235	BC	Cutting Permit 31	50	5,125	68	44.5	23.2
3261	OR	Wallowa-Whitman NF	45	4,650	91	39.8	18.5
3229	BC	Powers Creek	50	4,100	77	39.8	18.1
3250	NM	Santa Fe NF	36	9,500	69	39.4	16.5
3253	ID	Payette NF	45	6,200	77	39.4	18.9
3258	WA	Okanogan NF	48	4,200	77	36.2	16.9
3629	CO	Grand Mesa-Uncompahgre NF	39	10,500	71	32.3	14.6
3259	WA	Wenatchee NF	48	2,550	52	31.9	13.8
3252	AZ	Coconino NF	35	9,400	67	31.5	13.4
3248	CO	San Juan NF	37	10,600	69	31.1	15.7
3246	CO	Roosevelt NF	40	9,000	77	30.7	15.7
3249	CO	Gunnison NF	39	10,400	90	29.5	13.8
3621	CO	Larimer County #1	41	7,900	66	29.1	13.8
3247	CO	Pike NF	39	8,900	77	28.3	12.6
3256	UT	Dixie NF	37	9,900	85	26.8	14.2
3622	CO	Larimer County #2	41	9,400	83	26.4	13.0
3630	NM	Gila NF	33	8,200	62	24.0	5.9
3255	ID	Cache NF	42	8,500	67	21.3	10.6
Plantation Mean					73	33.9	15.7

[1]*Source means scored by the same line are not statistically different at the 5% level.*

of shade requirements, but an approximate 8- by 8-foot (2.4- by 2.4-m) grid was maintained.

During the first growing season, tree condition and survival observations were taken monthly. General vigor, presence and condition of new growth, and condition of old foliage were noted. Dead trees were dug up, and root condition was recorded.

Beginning in 1971, survival counts were taken twice yearly—once after snowmelt in the spring, and again in late fall after the onset of dormancy. Trees were reshaded at each visit until they outgrew the shading material.

Total height of each tree was measured to the nearest centimeter in the fall of 1974 and 1979, at the conclusion of the 5th and 10th growing seasons after planting. Ten-year height and survival were compared, using a randomized block analysis of variance.

Results

Survival

Survival of trees from all seed sources averaged 73% after 10 years (table 1). And, although survival among individual seed sources ranged from 52% for the Wenatchee source to 91% for the Wallowa-Whitman source, there were no statistically significant differences among sources in survival.

Initial rates of mortality were similar for all seed sources. Most mortality occurred during the first 2 years after planting. Survival rates for sources exhibiting the best, poorest, and average performance for all sources are illustrated in figure 1.

First season tree condition records indicate several factors responsible for initial mortality. Improper planting clearly contributed to 17% of the first season mortality, while poor root system development resulted

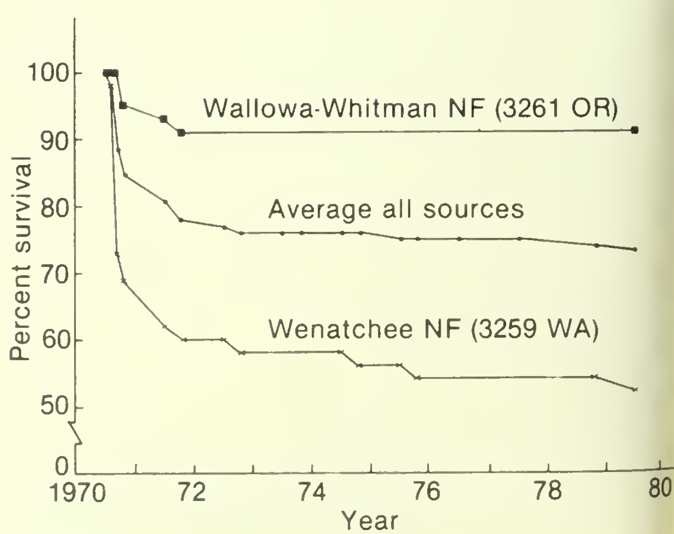


Figure 1.—Best, worst, and average survival by year.

in 15% of the first season losses. A combination of the above factors caused an additional 10% loss. Initial condition of the trees when planted may have been responsible for some of these losses. Only 11% of the trees which died the first growing season exhibited good vigor one month after planting. The remaining losses were due to unknown causes.

The lack of new foliage after planting also indicated which trees were under stress and most likely to die. Only 12% of the trees with healthy new growth one month after planting died during the first growing season, whereas new growth was dead on 34% of the trees which eventually died. In addition, 38% of the first season mortality had lost needles from the lower branches within 1 month after planting.

Height Growth

Average total height of trees, from all seed sources, after 10 years, was 33.9 inches (86 cm) (table 1). There were significant differences in total height among the 20 seed sources at 5 and 10 years after planting. After 10 years total height among individual seed sources ranged from 21.3 inches (54 cm) for the Cache NF source (3255) from Idaho to 47.6 inches (121 cm) for the Kidd Creek source (3231) from British Columbia. Individual tree heights ranged from 5.9 to 79.1 inches (15 to 201 cm) (fig. 2).

The four British Columbia seed sources did quite well, averaging from 39.7 to 47.6 inches (101 cm to 121 cm) in height. Significant differences in height were found between the top British Columbia seed source and the Cache, Gila, Larimer County, and Dixie sources. The Cache source was also significantly shorter than the Payette, Santa Fe, Wallowa-Whitman, and all British Columbia sources (table 1).

Latitude and elevation of the seed sources were both related to height growth. Analysis of variance of grouped data revealed significant differences in height between low and high elevation sources and between northern and southern sources (figs. 3 and 4). In contrast, there were no significant differences in survival of sources grouped on the basis of latitude or elevation of seed source. Because seed from all sources from below 6,900 feet (2,100 m) elevation were also from northern latitudes ($\geqq$ 45° N), it is impossible to determine if either or both of these variables are responsible for differences in height growth among groups of sources.

Relative height growth for most sources has not changed much during the course of this study. In general, northern sources grew relatively well throughout the entire study period. The most notable of these are the four sources from British Columbia, and the sources from the Wallowa-Whitman NF (3261) in Oregon, and from the Payette NF (3253) in Idaho. These sources were ranked between 3rd and 15th out of 20 in total height in the nursery. However, their relative height growth improved after planting and the same sources were ranked between 1st and 7th position at 5 and 10 years after planting. While height growth of

Figure 2.—This tree from the Wallowa-Whitman seed source was 79 inches (201 cm) tall, 10 growing seasons after planting.

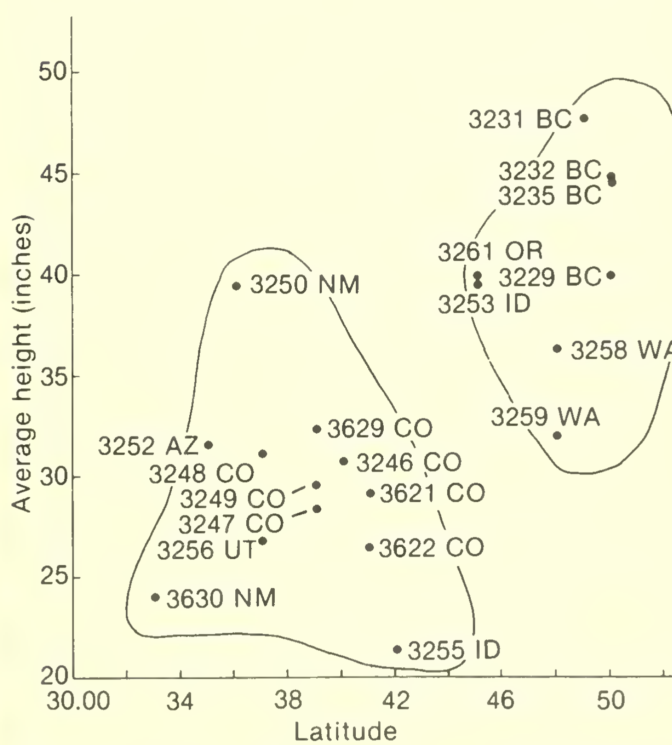


Figure 3.—Average height growth by latitude of seed source. Northern sources were significantly taller than southern sources (circled areas).

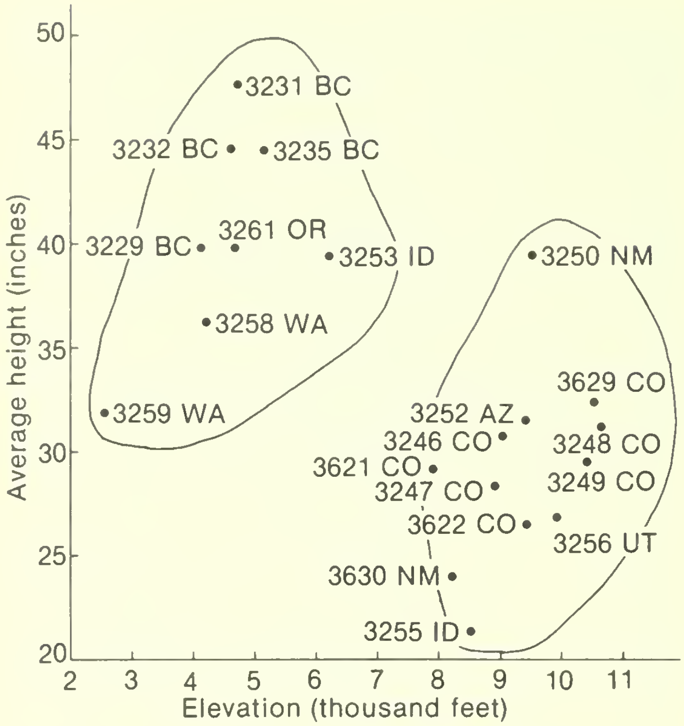


Figure 4.—Average height growth by elevation of seed source. Low and high elevation sources (circled) were significantly different.

trees from all sources averaged 15.7 inches (40 cm) (table 1) for the period between 5 and 10 years after planting, height growth of trees from the six sources above averaged between 18.1 and 24.8 inches (46 and 63 cm) during the same period.

In contrast to the northern sources, most of the southern (less than 43° N latitude) sources have grown slowly during the entire study period. Height growth during the last 5 years, for 9 of the southern sources, averaged between 5.9 and 14.6 inches (15 and 37 cm). The most notable exception to the generalization that southern sources have shown consistent slow growth during the study period is the Gila NF source (3630) from New Mexico. This source ranked first out of 20 in height in the nursery, but dropped to 11th after 5 years in the field, and to 19th after 10 years.

Discussion and Conclusions

It is not uncommon for high altitude Engelmann spruce plantations in the Rockies to fail dismally because of environmental and biotic factors. However, in this study none of the sources had less than 50% survival after 10 seasons of growth. The survival trends observed thus far indicate that it is possible to predict the eventual success of a plantation as early as 2 years after planting (fig. 1). The condition of the planting stock 1 month after planting also seems to be an indicator of eventual survival, but is less reliable. Such evidence suggests that trees in which new growth is absent or dead, or which shed needles shortly after planting, are not likely to survive the first growing season under the harsh conditions found on high altitude planting sites.

The lack of significant differences in survival of the 20 seed sources may not continue much longer. The physical appearance of trees from some sources indicates that more trees may die during the next few years. Trees from sources such as the Gila (fig. 5) seem to be gradually declining, as indicated by dead tops, lack of any well defined terminal leader, and poor growth form. It is possible that trees from some of the sources cannot adapt to environmental conditions of the site once they have grown beyond the protection of shading material.

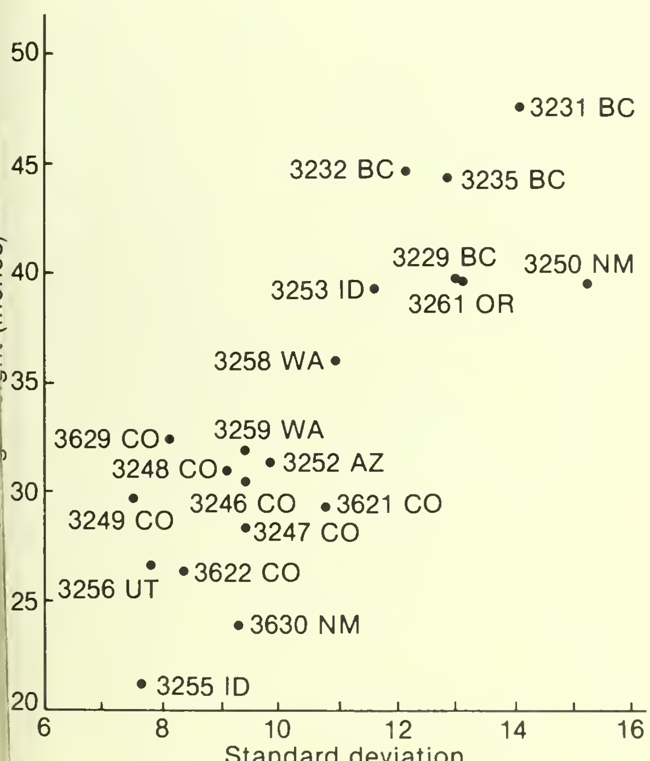
Height growth of trees in this plantation is not exceptional by standards used in other parts of the country. However, growth of many of the sources can be considered quite good for high altitudes in the central Rockies, where it is generally accepted that 20-40 years are necessary to achieve breast height of 4.5 feet (1.4 m) (Alexander 1967).

Height growth patterns found in this plantation probably are strongly correlated with phenological patterns such as time of flushing, and time of height growth cessation of individual seed sources. The dramatic change in height growth ranking of the Gila NF source (3630) is probably because the source is the southernmost in this study, and trees from this source have suffered repeated severe winter damage (fig. 5). Height growth of trees from this source has averaged only 5.9 inches (15 cm) during the past 5 years. Other studies of the Engelmann-white spruce complex have shown that high elevation spruce sources are the first

Figure 5.—Trees from the Gila seed source, with dead tops, dying foliage, and poor form, are surviving, but do not appear to be well adapted to the site.

:o flush in the spring (Dietrichson 1971), the first to set oud in the fall (Roche 1969 and Dietrichson 1971), and are the slowest growing (Roche 1969, Dietrichson 1971, Nienstaedt et al. 1971). These studies appear to explain the slow growth of high elevation sources planted n this study. However, it should be noted that sources ermed low elevation in this study are actually from the ame elevation as the higher elevation sources in Roche's (1969) study, and that the study site is at a higher elevation and lower latitude than the earlier tudy sites. Additional research is needed in this plantation to determine the relationship between height growth and phenological variables.

Variation in height of individual trees within the ources increased as the average height of the source ncreased (fig. 6). This reflects individual tree behavior, in that all trees in the faster growing sources were not tall. In fact, some were as short or shorter than trees from slower growing sources. It is possible that outstanding growth of some trees in northern seed ources may be attributed to hybrid vigor resulting rom introgression of Engelmann and white spruce. Dietrichson (1971), for example, attributed the outstanding vigor of British Columbia sources planted n Norway to heterosis resulting from introgression of he two species. Before testing this hypothesis, owever, additional research using techniques such as hose described by Fowler and Roche (1977) will be required to determine if some of the sources included in his study are of hybrid origin.



F ure 6.—Sources with taller average tree height exhibited reater variation in individual tree height.

A major factor contributing to the success of this plantation was the care taken in handling, planting, and shading each tree, and the replacement of shade during the subsequent biannual inspections. Continued protection and careful recordkeeping also contributed greatly to the success of this study.

This study demonstrates not only that Engelmann spruce planting stock may be improved genetically, but that the species can be successfully planted at high altitudes when proper procedures are carefully followed.

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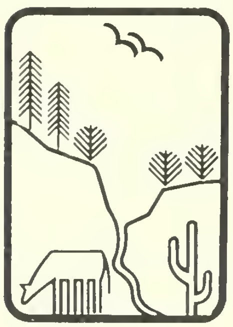
Rocky Mountains



Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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Volume Tables and Point-Sampling Factors for Aspen in Colorado

Carleton B. Edminster,
H. Todd Mowrer, and
Thomas E. Hinds

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U.S. Department of Agriculture

USDA Forest Service
Research Paper RM-232

February 1982

Volume Tables and Point-Sampling Factors for Aspen in Colorado[1]

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Abstract

Volume tables present total cubic feet, merchantable cubic feet to 4-inch top, metric equivalents of cubic volume, and board feet Scribner and International ¼-inch Rules to 6-inch top. Point-sampling factor tables give merchantable volumes per square foot of basal area. Tree heights are expressed as total height and merchantable number of logs.

[1]This paper supersedes Research Note 63, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.
[2]Station headquarters is in Fort Collins, in cooperation with Colorado State University.

Volume Tables and Point-Sampling Factors for Aspen in Colorado

Carleton B. Edminster, H. Todd Mowrer, and Thomas E. Hinds

Management Highlights

Eleven tables presented here give values and equations needed to determine the gross volumes of aspen (*Populus tremuloides* Michx.) trees in Colorado. The ables provide:

1. Gross volumes, in cubic feet, of the entire stem.
2. Gross merchantable volumes, in cubic feet, to a 4-inch top.
3. Gross merchantable volumes, in board feet, Scribner and International ¼-inch Rules, to a 6-inch top.
4. Point-sampling factors giving merchantable volumes in cubic feet and board feet per square foot of basal area.

Sample tree measurements for this study come from previous studies of decay (Davidson et al. 1959; Hinds 1963) and tree volume (Peterson 1961) and the USDA Forest Service Rocky Mountain Region inventory. Trees were sampled on the Arapaho, Roosevelt, Grand Mesa, Uncompahgre, Gunnison, Routt, San Juan, and White River National Forests in Colorado.

Stand volumes on an area may be determined from: 1) measurements of all tree diameters and heights, (2) neasurements of all tree diameters and sufficient ıeights to convert the appropriate volume tables to ocal volume tables (Chapman and Meyer 1949), or (3) ree tallies obtained by point sampling.

Definitions and Standards

Diameter at breast height (d.b.h.)—Measured to the earest 0.1 inch, outside the bark, at 4.5 feet above round level, on the uphill side of the tree. Full-inch-iameter classes, with class midpoints at the ½-inch ıarks, are used in the tables.

Total height.—Measured, in whole feet to the nearst foot, from ground level on the uphill side of the tree pward to the tip. Trees forked below utilization limits escribed below, dead-topped, with excessive limbiess, or severely deformed were not included in the ample. The midpoints of total height classes in the ıbles are multiples of 10 feet.

Scaling diameter of logs.—Average diameter inside ırk to nearest 0.1 inch, measured at the small end of lgs or half-logs.

Minimum top diameters for merchantable volumes.—Minimum top diameter inside bark for computation of merchantable cubic-foot volume was 4 inches. For board-foot volume, a minimum top diameter inside bark of 6 inches was used to conform to local practice. Logs with a scaling diameter smaller than 5.6 inches usually were not included in saw-log volume. A few logs with smaller scaling diameters were included to satisfy the "4-foot rule" described below.

Merchantable length in logs.—Measured from 1 foot above ground level on the uphill side of the tree, upward to the limit of saw-log utilization. Each tree was sectioned into as many 16.5-foot long logs as possible. An additional half-log, if available, was taken from the uppermost part of the merchantable length. Portions of the bole above the height of minimum top diameter inside bark were included in the uppermost saw-log if the standard log or half-log length ended within 4 feet above this height. This "4-foot rule" was used to avoid a negative bias in volume determination (Chapman and Meyer 1949).

Explanation of Tables

General definitions and standards given above apply to all tables listed in the appendix. Explanation of each type of table and suggestions for use follow.

Volume Tables

Headings and footnotes of each volume table (table 1 and even-numbered tables 2 through 10) give units of volume and height measurement, utilization standards, and volume equations used in compilation. Full-inch-diameter classes and 10-foot-height classes or half-log-length classes were used in all tables in American Standard units.

The volume tables were developed from linear regressions of V and D^2H or D^2L of the form:

$$V = a + bD^2H \text{ or } V = a + bD^2L$$

where:

V = gross volume inside bark in the appropriate unit
D = d.b.h. outside bark in inches
H = total height in feet
L = merchantable length in standard logs and half-logs
a,b = regression coefficients

Graphs of V versus D^2H or D^2L for all volume relationships indicated a slight nonlinear trend. Two linear regression equations were used to cover the full range of the basic data. Unfortunately, the linear regression equations for board-foot volumes gave negative estimates for small values of D^2H. To correct this, the volume of a half-log with minimum top diameter of 6 inches inside bark has been substituted as described in the footnotes for tables 4 and 8.

The number of logs in a tree shown in tables 6 and 10 is not necessarily the number that will actually be cut from it. It is the number of logs between the 1-foot above ground level and the height of minimum top diameter. Volume of nonmerchantable logs below the height of minimum top diameter should be deducted from tree volume by: (1) estimation of scaling diameters and deduction of appropriate log volumes, or (2) use of taper tables to determine scaling diameters and deduction of log volumes. Volume should not be reduced by tallying fewer logs in the tree.

Point-Sampling Factors

Odd-numbered tables from tables 3 through 11 give point-sampling factors for combinations of tree d.b.h. and height or merchantable length. Tabulated volumes per square foot of basal area were obtained from equations given in the table footnotes. These equations were derived by dividing each term of the corresponding tree volume equation by tree basal area in square feet ($B = 0.0054542D^2$).

Point-sample cruising to estimate stand volume can be done in several ways: (1) measure the d.b.h. and height of each tree tallied through the prism, angle gage, or relascope; (2) measure the height of each tallied tree and estimate its d.b.h.; or (3) measure the heights of the tallied trees and make no record of d.b.h.'s. The procedure selected will depend on the precision desired. Relative precision is usually in the order listed above. If the d.b.h. and height of each tallied tree are measured, a volume conversion factor can be selected from the tables or computed from the appropriate equations for each combination of d.b.h. and height.

Volume per acre is then computed as follows:

1. Multiply the number of tallied trees in each d.b.h.-height class by the point-sampling factor for the class.
2. Total the products of step 1.
3. Multiply the total of step 2 by the basal area factor of the angle gage used.
4. Divide the product of step 3 by the number of points sampled on the tract.

Considerable time often can be saved if the heights of tallied trees are measured, while d.b.h.'s are estimated and recorded by broad classes. Inspection of the point-sampling factor tables shows that volumes per square foot of basal area, for trees larger than 12 inches d.b.h., often do not differ greatly among trees of a single height class. The increased time spent measuring d.b.h.'s may not increase precision materially. When the distribution of d.b.h.'s and heights inventoried indicates there is little change in volume per square foot within a height class, it is recommended that d.b.h.'s not be recorded at all. Point-sampling factors for each height class can be computed using a procedure similar to deriving a local volume table from a standard table (Chapman and Meyer 1949).

The techniques of point sampling have been described in numerous publications (Dilworth and Bell 1971; Grosenbaugh 1958). Procedures for computing tree volumes and point-sampling factors using programmable calculators have been developed by Shepperd (1980).

Metric Equivalents for Cubic Volume

Tables 12 and 13 are the metric equivalents of tables 1 and 2 for total and merchantable cubic volume, respectively. Equations used in developing the metric tables are given in the footnotes to tables 12 and 13. These equations are conversions (Myers and Edminster 1974) of the equations in American Standard units from tables 1 and 2. The form of the equations is:

$$V_m = a_m + b_m D_m{}^2 H_m$$

where:

V_m = gross volume inside bark in cubic meters
D_m = d.b.h. outside bark in centimeters
H_m = total height in meters
a_m, b_m = metric conversions of regression coefficients a, b

Table 14 gives point-sampling factors for gross merchantable volume in cubic meters per square meter of basal area. The equations used to develop table 14 were derived by dividing each term of the volume equations of table 13 by tree basal area in square meters ($B_m = 0.00007854D_m{}^2$).

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Appendix

Table 1.—Gross volumes, in cubic feet inside bark, of entire stem including stump and top, aspen in Colorado

d.b.h.	Total height (feet) above ground										Basis: trees
	10	20	30	40	50	60	70	80	90	100	
inches											
2	0.1	0.3									0
3	0.3	0.5	0.8	1.1	1.4						0
4	0.4	0.9	1.3	1.8	2.2	2.7					79
5	0.7	1.3	2.0	2.7	3.4	4.0	4.7				106
6		1.9	2.8	3.8	4.7	5.6	6.6	7.5			102
7		2.5	3.7	5.0	6.2	7.5	8.7	10.0			94
8		3.2	4.8	6.4	8.0	9.6	11.2	12.8			84
9			6.0	8.0	10.0	12.0	14.0	16.0			107
10			7.3	9.8	12.2	14.7	17.1	19.6	22.0		96
11			8.8	11.7	14.7	17.6	20.5	23.5	26.4		82
12			10.4	13.9	17.3	20.8	24.3	27.7	30.7		92
13				16.2	20.2	24.3	28.2	31.7	35.1	38.6	78
14				18.7	23.2	27.9	31.9	35.9	39.9	43.9	56
15				21.3	26.7	31.4	35.9	40.5	45.0	49.6	50
16				24.2	29.8	35.0	40.2	45.3	50.5	55.6	37
17					33.1	38.9	44.7	50.5	56.3	62.1	27
18					36.5	43.0	49.5	55.9	62.4	68.9	17
19					40.1	47.3	54.5	61.7	68.9	76.1	14
20					43.9	51.8	59.8	67.8	75.7	83.7	8
21					47.9	56.6	65.4	74.1	82.9	91.7	5
22						61.6	71.2	80.8	90.4	100.0	3
23						66.9	77.3	87.8	98.3	108.7	2
24						72.3	83.7	95.1	106.5	117.8	0
25							90.3	102.7	115.0	127.3	0
Basis: trees	0	5	47	150	162	278	322	138	31	6	1139

Block indicates extent of data.
Computed from: $V = 0.002219D^2H$ for D^2H to 12,470;
$V = 0.001896D^2H + 4.0267$ for D^2H larger than 12,470
Standard errors of estimate: ±1.25 cubic feet (±11.33% of mean); ±4.72 cubic feet (±12.97% of mean)
Coefficients of determination: 0.9914; 0.8826
Diameter classes full-inch (e.g., 20-inch class includes 20.0 to 20.9 inches d.b.h.)

Table 2.—Gross merchantable volumes, in cubic feet inside bark, merchantable stem excluding stump and top, aspen in Colorado. Top diameter 4 inches inside bark. Stump height 1 foot

d.b.h.	Total height (feet) above ground									Basis: trees
	20	30	40	50	60	70	80	90	100	
inches										
5	0.4	1.1	1.7	2.4	3.1	3.7				106
6	0.9	1.9	2.8	3.7	4.7	5.6	6.5			102
7	1.6	2.8	4.0	5.3	6.5	7.7	9.0			94
8	2.3	3.8	5.4	7.0	8.6	10.2	11.8			84
9		5.0	7.0	9.0	11.0	13.0	14.9			107
10		6.4	8.8	11.2	13.6	16.0	18.4	20.9		96
11		7.8	10.7	13.6	16.5	19.4	22.3	25.2		82
12		9.4	12.8	16.2	19.7	23.1	26.3	29.1		92
13			15.1	19.1	23.1	26.7	30.1	33.4	36.8	78
14			17.5	22.2	26.5	30.4	34.2	38.1	41.9	56
15			20.2	25.4	29.8	34.2	38.6	43.0	47.5	50
16			23.0	28.3	33.3	38.3	43.3	48.3	53.3	37
17				31.4	37.1	42.7	48.3	54.0	59.6	27
18				34.8	41.0	47.3	53.6	59.9	66.2	17
19				38.2	45.2	52.2	59.2	66.2	73.2	14
20				41.9	49.6	57.4	65.1	72.8	80.5	8
21				45.8	54.3	62.8	71.3	79.8	88.2	5
22					59.1	68.4	77.7	87.0	96.3	3
23					64.2	74.3	84.5	94.6	104.8	2
24					69.5	80.5	91.5	102.6	113.6	0
25						86.9	98.9	110.8	122.8	0
Basis: trees	1	18	111	155	278	322	138	31	6	1060

Block indicates extent of data.
Computed from: $V = 0.002195D^2H - 0.9076$ for D^2H to 11,800;
$V = 0.001837D^2H + 3.3075$ for D^2H larger than 11,800
Standard errors of estimate: ± 1.34 cubic feet (± 12.13% of mean); ± 4.66 cubic feet (± 13.42% of mean)
Coefficients of determination: 0.9670; 0.8790
Diameter classes full-inch (e.g., 20-inch class includes 20.0 to 20.9 inches d.b.h.)

Table 3.—Gross merchantable volumes, in cubic feet inside bark per square foot of basal area, merchantable stem excluding stump and top, aspen in Colorado. Top diameter 4 inches inside bark. Stump height 1 foot

	Total height (feet) above ground								
d.b.h.	20	30	40	50	60	70	80	90	100
inches									
5	2.5	6.6	10.6	14.6	18.6	22.7			
6	4.1	8.1	12.2	16.2	20.2	24.2	28.2		
7	5.1	9.1	13.1	17.2	21.2	25.2	29.2		
8	5.7	9.8	13.8	17.8	21.8	25.9	29.9		
9		10.2	14.3	18.3	22.3	26.3	30.3		
10		10.6	14.6	18.6	22.6	26.7	30.7	34.7	
11		10.8	14.8	18.9	22.9	26.9	30.9	34.9	
12		11.0	15.0	19.1	23.1	27.1	30.8	34.2	
13			15.2	19.2	23.2	26.9	30.3	33.6	37.0
14			15.3	19.3	23.1	26.5	29.8	33.2	36.6
15			15.4	19.4	22.7	26.1	29.5	32.8	36.2
16			15.5	19.1	22.4	25.8	29.2	32.5	35.9
17				18.8	22.2	25.6	28.9	32.3	35.7
18				18.6	22.0	25.4	28.7	32.1	35.5
19				18.4	21.8	25.2	28.5	31.9	35.3
20				18.3	21.7	25.0	28.4	31.8	35.1
21				18.2	21.5	24.9	28.3	31.6	35.0
22					21.4	24.8	28.1	31.5	34.9
23					21.3	24.7	28.0	31.4	34.8
24					21.2	24.6	28.0	31.3	34.7
25						24.5	27.9	31.3	34.6

Computed from: $V/B = 0.40236H - 166.41002/D^2$ for D^2H to 11,800;
$V/B = 0.33689H + 606.42083/D^2$ for D^2H larger than 11,800
Diameter classes full-inch (e.g., 20-inch class includes 20.0 to 20.9 inches d.b.h.)

Table 4.—Gross volumes, in board feet, inside bark Scribner Rule, merchantable stem excluding stump and top, aspen in Colorado. Top diameter 6 inches inside bark. Stump height 1 foot

d.b.h.	Total height (feet) above ground 30	40	50	60	70	80	90	100	Basis: trees
inches									
7	8	8	12	18	24	31			94
8	8	12	21	29	37	45			84
9	10	21	31	41	51	62			107
10	17	30	42	55	67	80	91		96
11	25	40	55	70	84	98	112		82
12	33	51	68	86	102	118	134		92
13		63	83	102	121	140	158	177	78
14		75	97	119	141	163	184	206	56
15		88	113	138	163	188	212	237	50
16		101	130	158	186	214	242	270	37
17			147	179	210	242	274	306	27
18			166	201	237	272	307	343	17
19			185	225	264	303	343	382	14
20			206	250	293	336	380	423	8
21			228	276	323	371	419	467	5
22				303	355	408	460	512	3
23				331	389	446	503	560	2
24				361	423	485	548	610	0
25					460	527	594	661	0
Basis: trees	1	16	88	253	319	138	31	6	852

Block indicates extent of data.
Computed from: $V = 8$ for D^2H to 2,500;
$V = 0.011389D^2H - 20.5112$ for D^2H larger than 2,500 to 8,850;
$V = 0.010344D^2H - 11.2615$ for D^2H larger than 8,850
Standard errors of estimate: ± 7.1 board feet (± 16.73% of mean); ± 27.9 board feet (± 19.33% of mean)
Coefficients of determination: 0.9021; 0.8696
Diameter classes full-inch (e.g., 20-inch class includes 20.0 to 20.9 inches d.b.h.)

Table 5.—Gross volumes, in board feet inside bark Scribner Rule per square foot of basal area, merchantable stem excluding stump and top, aspen in Colorado. Top diameter 6 inches inside bark. Stump height 1 foot

d.b.h.	Total height (feet) above ground							
	30	40	50	60	70	80	90	100
inches								
7	26	26	38	58	79	100		
8	20	31	52	73	94	115		
9	21	42	63	84	104	125		
10	29	49	70	91	112	133	152	
11	34	55	76	97	117	136	155	
12	39	59	80	101	120	139	157	
13		63	83	102	121	140	159	178
14		66	85	104	123	142	161	180
15		67	86	105	124	143	162	181
16		68	87	106	125	144	163	182
17			88	107	126	145	164	183
18			89	108	127	146	165	184
19			89	108	127	146	165	184
20			90	109	128	147	166	185
21			90	109	128	147	166	185
22				110	129	148	167	186
23				110	129	148	167	186
24				110	129	148	167	186
25					130	149	168	186

Computed from: $V/B = 1466.75956/D^2$ for D^2H to 2500;
$V/B = 2.08807H - 3760.63347/D^2$ for D^2H larger than 2500 to 8850;
$V/B = 1.89648H - 2064.73599/D^2$ for D^2H larger than 8850
Diameter classes full-inch (e.g., 20-inch class includes 20.0 to 20.9 inches d.b.h.)

Table 6.—Gross volumes, in board feet inside bark Scribner Rule, merchantable stem excluding stump and top, aspen in Colorado. Top diameter 6 inches inside bark. Stump height 1 foot

d.b.h.	Number of 16-foot logs to 6-inch top										Basis: trees
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	
inches											
7	12	18	25	31	37	44					94
8	14	22	30	38	47	55	63				84
9	16	26	36	47	57	67	77	87			107
10	18	31	43	56	68	81	92	103			96
11		36	51	66	81	94	108	121	134		82
12		41	59	77	93	109	125	141	156		92
13		47	68	88	106	125	143	162	180		78
14			77	99	120	142	163	184	206		56
15			87	111	136	160	184	209	233	258	50
16			97	124	152	179	207	235	262	290	37
17				138	169	200	231	262	293	325	27
18				153	187	222	257	292	326	361	17
19				168	207	245	284	322	361	400	14
20				184	227	270	312	355	398	440	8
21				201	248	295	342	389	436	483	5
22					271	322	373	425	476	528	3
23						350	406	462	518	574	2
24						379	440	501	562	623	0
25							476	542	608	674	0
Basis: trees	44	77	85	150	169	184	87	34	21	1	852

Block indicates extent of data.
Computed from: $V = 0.227340D^2L + 5.5302$ for D^2L to 335;
$V = 0.203011D^2L + 13.6705$ for D^2L larger than 335
Standard errors of estimate: ±5.8 board feet (±12.23% of mean); ±25.9 board feet (±17.01% of mean)
Coefficients of determination: 0.9486; 0.8860
Diameter classes full-inch (e.g., 20-inch class includes 20.0 to 20.9 inches d.b.h.)

Table 7.—Gross volumes, in board feet inside bark Scribner Rule per square foot of basal area, merchantable stem excluding stump and top, aspen in Colorado. Top diameter 6 inches inside bark. Stump height 1 foot

d.b.h.	Number of 16-foot logs to 6-inch top									
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
inches										
7	39	60	81	101	122	143				
8	35	56	77	97	118	139	160			
9	32	53	74	95	115	136	157	177		
10	30	51	72	93	113	134	153	172		
11		49	70	91	112	131	149	168	186	
12		48	69	90	109	128	146	165	184	
13		47	68	88	107	125	144	163	181	
14			67	86	105	124	142	161	179	
15			66	85	103	122	141	159	178	197
16			65	84	102	121	139	158	177	195
17				83	101	120	138	157	176	194
18				82	100	119	138	156	175	193
19				81	100	118	137	155	174	193
20				80	99	118	136	155	173	192
21				80	98	117	136	154	173	192
22					98	117	135	154	172	191
23						116	135	153	172	191
24						116	134	153	172	190
25							134	153	171	190

Computed from: $V/B = 41.68167L + 1013.92605/D^2$ for D^2L to 335;
$V/B = 37.22097L + 2506.41169/D^2$ for D^2L larger than 335
Diameter classes full-inch (e.g., 20-inch class includes 20.0 to 20.9 inches d.b.h.)

Table 8.—Gross volumes, in board feet, inside bark International ¼-inch Rule, merchantable stem excluding stump and top, aspen in Colorado. Top diameter 6 inches inside bark. Stump height 1 foot

d.b.h.	Total height (feet) above ground								Basis: trees
	30	40	50	60	70	80	90	100	
inches									
7	9	9	12	20	27	35			94
8	9	13	23	33	43	52			84
9	11	23	35	47	60	72			107
10	19	34	49	64	78	93	108		96
11	28	46	63	81	99	117	134		82
12	38	59	80	101	122	141	160		92
13		73	97	122	144	166	188	210	78
14		88	116	143	168	193	218	243	56
15		104	135	164	193	222	251	279	50
16		121	155	187	220	253	285	318	37
17			175	212	248	285	322	359	27
18			197	238	279	320	361	402	17
19			219	265	311	356	402	447	14
20			243	294	344	394	445	495	8
21			268	324	379	435	490	546	5
22				356	416	477	538	598	3
23				389	455	521	587	654	2
24				423	495	567	639	711	0
25					537	615	693	771	0
Basis: trees	1	16	88	253	319	138	31	6	852

Block indicates extent of data.
Computed from: $V = 9$ for D^2H to 2,570;
$V = 0.013472D^2H - 25.5968$ for D^2H larger than 2,570 to 11,460;
$V = 0.011989D^2H - 8.6015$ for D^2H larger than 11,460
Standard errors of estimate: ±11.3 board feet (±17.09% of mean); ±36.0 board feet (±18.37% of mean)
Coefficients of determination: 0.9169; 0.8377
Diameter classes full-inch (e.g., 20-inch class includes 20.0 to 20.9 inches d.b.h.)

Table 9.—Gross volumes, in board feet inside bark International ¼-inch Rule per square foot of basal area, merchantable stem excluding stump and top, aspen in Colorado. Top diameter 6 inches inside bark. Stump height 1 foot

d.b.h.	Total height (feet) above ground							
	30	40	50	60	70	80	90	100
inches								
7	29	29	40	65	89	114		
8	23	34	59	83	108	133		
9	22	47	72	96	121	146		
10	32	56	81	106	130	155	180	
11	39	63	88	113	137	162	186	
12	44	69	93	118	143	166	188	
13		73	98	122	145	167	189	211
14		76	101	124	146	168	190	212
15		79	103	125	147	169	191	213
16		82	104	126	148	170	192	214
17			105	127	149	171	193	215
18			105	127	149	171	193	215
19			106	128	150	172	194	216
20			106	128	150	172	194	216
21			106	128	150	172	194	216
22				129	151	173	195	217
23				129	151	173	195	217
24				129	151	173	195	217
25					151	173	195	217

Computed from: $V/B = 1650.10451/D^2$ for D^2H to 2,570;
$V/B = 2.47003H - 4693.03478/D^2$ for D^2H larger than 2,570 to 11,460;
$V/B = 2.19816H - 1577.04824/D^2$ for D^2H larger than 11,460
Diameter classes full-inch (e.g., 20-inch class includes 20.0 to 20.9 inches d.b.h.)

Table 10.—Gross volumes, in board feet inside bark International ¼-inch Rule, merchantable stem excluding stump and top, aspen in Colorado. Top diameter 6 inches inside bark. Stump height 1 foot

d.b.h.	Number of 16-foot logs to 6-inch top: 0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	Basis: trees
inches											
7	13	20	28	35	43	50					94
8	15	25	34	44	54	63	73				84
9	17	29	41	54	66	78	90	102			107
10	20	35	50	64	79	94	109	123			96
11		41	58	76	94	111	129	147	162		82
12		47	68	89	110	131	151	169	187		92
13		54	78	103	127	151	172	193	214		78
14			90	118	146	171	195	219	244		56
15			102	134	164	191	219	247	275	303	50
16			115	151	182	214	245	277	308	340	37
17				166	202	237	273	308	344	379	27
18				183	223	262	302	342	381	421	17
19				201	245	289	333	377	421	465	14
20				219	268	316	365	414	462	511	8
21				239	292	346	399	453	506	560	5
22					318	376	435	493	552	611	3
23						408	472	536	600	664	2
24						441	511	580	650	719	0
25							551	627	702	777	0
Basis: trees	44	77	85	150	169	184	87	34	21	1	852

Block indicates extent of data.
Computed from: $V = 0.267908D^2L + 5.2059$ for D^2L to 535;
$V = 0.231473D^2L + 24.6295$ for D^2L larger than 535
Standard errors of estimate: ±9.7 board feet (±13.58% of mean); ±34.6 board feet (±16.18% of mean)
Coefficients of determination: 0.9472; 0.8480
Diameter classes full-inch (e.g., 20-inch class includes 20.0 to 20.9 inches d.b.h.)

Table 11.—Gross volumes, in board feet inside bark International ¼-inch Rule per square foot of basal area, merchantable stem excluding stump and top, aspen in Colorado. Top diameter 6 inches inside bark. Stump height 1 foot

	Number of 16-foot logs to 6-inch top									
d.b.h.	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**
inches										
7	42	66	91	115	140	164				
8	38	62	87	111	136	161	185			
9	35	60	84	109	133	158	182	207		
10	33	58	82	107	131	156	181	205		
11		56	81	105	130	155	179	204	225	
12		55	80	104	129	153	177	199	220	
13		54	79	103	128	152	173	195	216	
14			78	103	127	149	170	191	212	
15			78	102	125	146	167	189	210	231
16			77	101	123	144	165	186	208	229
17				100	121	142	163	185	206	227
18				98	119	141	162	183	204	225
19				97	118	139	160	182	203	224
20				96	117	138	159	181	202	223
21				95	116	137	158	180	201	222
22					115	136	157	179	200	221
23						135	157	178	199	220
24						135	156	177	199	220
25							155	177	198	219

Computed from: $V/B = 49.11964L + 954.46831/D^2$ for D^2L to 535;
$V/B = 42.43941L + 4515.68811/D^2$ for D^2L larger than 535
Diameter classes full-inch (e.g., 20-inch class includes 20.0 to 20.9 inches d.b.h.)

Table 12.—Gross volumes, in cubic meters inside bark, of entire stem including stump and top, aspen in Colorado

d.b.h.	3	6	9	12	15	18	21	24	27	30
	Total height (meters) above ground									
cm										
6	0.003	0.01								
8	.01	.01	0.02	0.02	0.03					
10	.01	.02	.03	.04	.05	0.06				
12	.01	.03	.04	.06	.07	.08				
14		.04	.06	.08	.09	.11	0.13			
16		.05	.07	.10	.12	.15	.17	0.20		
18		.06	.09	.12	.16	.19	.22	.25		
20		.08	.12	.15	.19	.23	.27	.31		
22		.09	.14	.19	.23	.28	.32	.37		
24			.17	.22	.28	.33	.39	.44		
26			.19	.26	.32	.39	.45	.52	0.58	
28			.23	.30	.38	.45	.53	.60	.68	
30			.26	.35	.43	.52	.60	.69	.78	
32				.39	.49	.59	.69	.79	.87	0.95
34				.44	.55	.66	.78	.87	.97	1.06
36				.50	.62	.75	.86	.96	1.07	1.18
38				.55	.69	.82	.94	1.06	1.18	1.30
40				.61	.77	.90	1.03	1.16	1.29	1.42
42				.68	.84	.98	1.13	1.27	1.41	1.56
44					.91	1.07	1.22	1.38	1.54	1.70
46					.98	1.15	1.33	1.50	1.67	1.85
48					1.06	1.25	1.44	1.62	1.81	2.00
50					1.14	1.34	1.55	1.75	1.96	2.16
52					1.22	1.44	1.66	1.89	2.11	2.33
54					1.31	1.55	1.79	2.02	2.26	2.50
56						1.66	1.91	2.17	2.43	2.68
58						1.77	2.04	2.32	2.59	2.87
60						1.88	2.18	2.47	2.77	3.06
62						2.00	2.32	2.63	2.95	3.26
64							2.46	2.80	3.13	3.47

Block indicates extent of data.

Computed from: $V_m = 0.0000320 D_m{}^2 H_m$ for $D_m{}^2 H_m$ to 24,520

$V_m = 0.0000273 D_m{}^2 H_m + 0.11402$ for $D_m{}^2 H_m$ larger than 24,520

Table 13.—Gross merchantable volumes, in cubic meters inside bark, merchantable stem excluding stump and top, aspen in Colorado. Top diameter 10 cm inside bark. Stump height 0.3 m.

d.b.h.	Total height (meters) above ground								
	6	9	12	15	18	21	24	27	30
cm									
14	0.01	0.03	0.05	0.07	0.09	0.10			
16	.02	.05	.07	.10	.12	.14	0.17		
18	.04	.07	.10	.13	.16	.19	.22		
20	.05	.09	.13	.16	.20	.24	.28		
22	.07	.11	.16	.20	.25	.30	.34		
24		.14	.19	.25	.30	.36	.41		
26		.17	.23	.29	.36	.42	.49	0.55	
28		.20	.27	.35	.42	.49	.57	.64	
30		.23	.32	.40	.49	.57	.66	.74	
32			.36	.46	.56	.65	.74	.83	0.91
34			.41	.52	.63	.74	.83	.92	1.01
36			.47	.59	.71	.81	.92	1.02	1.12
38			.52	.66	.78	.90	1.01	1.13	1.24
40			.58	.73	.86	.98	1.11	1.24	1.36
42			.64	.79	.93	1.07	1.21	1.35	1.49
44				.86	1.02	1.17	1.32	1.48	1.63
46				.93	1.10	1.27	1.44	1.61	1.77
48				1.01	1.19	1.37	1.56	1.74	1.92
50				1.09	1.28	1.48	1.68	1.88	2.08
52				1.17	1.38	1.60	1.81	2.03	2.24
54				1.25	1.48	1.71	1.95	2.18	2.41
56					1.59	1.84	2.09	2.33	2.58
58					1.70	1.96	2.23	2.50	2.76
60					1.81	2.09	2.38	2.67	2.95
62					1.92	2.23	2.53	2.84	3.14
64						2.37	2.69	3.02	3.34

Block indicates extent of data.

Computed from: $V_m = 0.0000316 D_m{}^2 H_m - 0.02570$ for $D_m{}^2 H_m$ to 23,200

$V_m = 0.0000265 D_m{}^2 H_m + 0.09366$ for $D_m{}^2 H_m$ larger than 23,200

Table 14.—Gross merchantable volumes, in cubic meters inside bark per square meter of basal area, merchantable stem excluding stump and top, aspen in Colorado. Top diameter 10 cm inside bark. Stump height 0.3 m

d.b.h.	Total height (meters) above ground								
	6	9	12	15	18	21	24	27	30
cm									
14	0.74	1.95	3.16	4.37	5.57	6.78			
16	1.14	2.34	3.55	4.76	5.96	7.17	8.38		
18	1.40	2.61	3.82	5.03	6.23	7.44	8.65		
20	1.60	2.80	4.01	5.22	6.42	7.63	8.84		
22	1.74	2.95	4.15	5.36	6.57	7.77	8.98		
24		3.05	4.26	5.47	6.67	7.88	9.09		
26		3.14	4.34	5.55	6.76	7.97	9.17	10.38	
28		3.20	4.41	5.62	6.83	8.03	9.24	10.45	
30		3.26	4.46	5.67	6.88	8.09	9.29	10.42	
32			4.51	5.72	6.92	8.13	9.25	10.26	11.27
34			4.55	5.75	6.96	8.11	9.12	10.13	11.14
36			4.58	5.78	6.98	7.99	9.01	10.02	11.03
38			4.60	5.81	6.89	7.90	8.91	9.92	10.93
40			4.62	5.80	6.81	7.82	8.83	9.84	10.85
42			4.64	5.73	6.74	7.75	8.76	9.77	10.78
44				5.67	6.68	7.69	8.70	9.71	10.72
46				5.62	6.63	7.64	8.65	9.66	10.67
48				5.57	6.58	7.59	8.60	9.61	10.62
50				5.53	6.54	7.55	8.56	9.57	10.58
52				5.49	6.51	7.52	8.53	9.54	10.55
54				5.46	6.47	7.48	8.49	9.51	10.52
56					6.44	7.45	8.47	9.48	10.49
58					6.42	7.43	8.44	9.45	10.46
60					6.40	7.41	8.42	9.43	10.44
62					6.37	7.38	8.40	9.41	10.42
64						7.37	8.38	9.39	10.40

Computed from: $V_m/B_m = 0.40236H_m - 327.23860/D_m^2$ for $D_m^2H_m$ to 23,200

$V_m/B_m = 0.33689H_m + 1192.50213/D_m^2$ for $D_m^2H_m$ larger than 23,200

Edminster, Carleton B., H. Todd Mowrer, and Thomas E. Hinds. 1981. Volume tables and point-sampling factors for aspen in Colorado. USDA Forest Service Research Paper RM-232, 16 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Volume tables present total cubic feet, merchantable cubic feet to 4-inch top, metric equivalents of cubic volume, and board feet Scribner and International ¼-inch Rules to 6-inch top. Point-sampling factor tables give merchantable volumes per square foot of basal area. Tree heights are expressed as total height and merchantable number of logs.

Keywords: tree volume tables, point-sampling factors, stand volume estimates, *Populus tremuloides*

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Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

Estimating Ponderosa Pine Fuel Moisture Using National Fire-Danger Rating Moisture Values

Michael G. Harrington

Research Paper RM-233
Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture

USDA Forest Service
Research Paper RM-233

June 198

Estimating Ponderosa Pine Fuel Moisture Using National Fire-Danger Rating Moisture Values

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Rocky Mountain Forest and Range Experiment Station[1]

Abstract

Comparisons were made between moisture contents of natural ponderosa pine fuels and the corresponding timelag moisture values calculated using the National Fire-Danger Rating System. The two variables correlated well at the driest moisture levels, but precipitation influenced each differently. Empirically derived equations permit adequate estimates of actual fuel moisture for burning projects.

Acknowledgement

Acknowledgement is made to Mary Wheat and Aaron Gelobter, formerly fuels management technicians with the Santa Catalina Ranger District, for their assistance in fuel sampling and weather station maintenance.

[1]Headquarters is in Fort Collins, in cooperation with Colorado State University. Research reported here was conducted at the Station's Research Work Unit at Tempe, in cooperation with Arizona State University.

Estimating Ponderosa Pine Fuel Moisture Using National Fire-Danger Rating Moisture Values

Michael G. Harrington

Management Implications

National forests maintain fire weather stations to monitor changing weather conditions for fire-danger forecasting. The weather elements, together with fuel moisture contents estimated from them, indicate potential wildfire behavior. This study compared actual fuel moisture contents from a ponderosa pine (*Pinus ponderosa* var. *arizonica*) stand in southeastern Arizona to calculated fuel moisture contents from the National Fire-Danger Rating System (NFDRS) using data from nearby weather stations. These comparisons were used to evaluate the accuracy of the fuel moisture models in estimating actual fuel moisture and to develop equations, utilizing NFDRS moisture values, which would provide better estimates of fuel moisture for use in prescribed fire planning.

The moisture content of the L (litter) layer needles is important in determining whether ignition will occur and how intensely and rapidly a fire will burn in these natural fuels. Calculated 1-hour timelag fuel moisture (1-h TL FM) proved to be a good indicator of L layer needle moisture below 10%. At the moist end of the data range, where fuels had been recently influenced by precipitation, the correlation held but the one-to-one relationship failed. One-half-inch fuel stick moisture also correlated well with L layer needle moisture. Because precipitation affected the moisture content of the fuel sticks and L layer needles differently, an equation was developed for the data not influenced by precipitation as well as for the entire data range. These equations proved to be the most accurate estimators of L layer moisture content; the equation for the fuel stick moisture range of 3% to 12% should be used when rain has not been a factor for at least 24 hours.

Within certain weather limits, the moisture content of the H (humus) layer determines how much of the forest floor will be consumed by fire. H layer moisture content can be estimated using 100-h TL FM and the developed equation.

Fair agreement was found between the moisture content of smaller woody fuels and the corresponding NFDRS timelag fuel moisture content. In all cases, a one-to-one relationship between actual and calculated moisture contents was not found where precipitation was influential. However, at the lowest moisture levels when there had been no precipitation for 24 hours, the one-to-one relationship was approached.

Even though the NFDRS moisture estimates were not exact over the entire moisture range for this study site, these estimates were quite accurate under the drier conditions. This is where precise information concerning potential wildfire behavior is critical. In addition, the equations presented here seem to be sufficiently accurate to estimate fuel moisture conditions which, when combined with weather data, could be very useful in prescribed burning. The equations should be applicable to southeastern Arizona ponderosa pine stands similar to those described here. Application to other areas will require further testing.

Introduction

Fuel moisture is one of the most important parameters determining fuel ignitability, rate of combustion, and amount of consumption. To estimate wildfire behavior variables, such as fire intensity, flame lengths, and rate of spread, the moisture content of the fuels involved must be known (Albini 1976). The moisture contents of various size fuels are also key values for the National Fire-Danger Rating System (Deeming et al. 1977). In addition, fuel moisture plays a major role in determining the success of prescribed fire. Amount of fuel consumption has been directly related to fuel moisture in understory burning in the Southeast (Hough 1968), the Northeast (Van Wagner 1972), the Northwest (Norum 1977), and the Southwest (Harrington 1981).

Attempts have been made to correlate calculated fire danger or hazard indices with actual fuel moisture contents, so that readily available and reliable moisture estimations could be made. Morris (1966) offered guidelines for predicting successful slash burning in the Pacific Northwest using fuel moisture stick values. In British Columbia, poor relationships were found between hazard stick readings and slash moisture contents simply because the wetting and drying characteristics of the sticks were unlike those of the slash (Péck 1969). A fair correlation was shown between the buildup index of the 1964 NFDRS and duff moisture of southeastern pine stands (Johnson 1968). Bradshaw (1978) reported weak relationships between duff moisture in western Montana western larch—Douglas-fir (*Larix occidentalis* - *Pseudotsuga menziesii*) stands and the 10-, 100-, 1,000-hour timelag moisture values, the buildup index, and the energy release component of the 1978 NFDRS. In a field test of a duff moisture prediction model based on weather parameters, Frandsen and Bradshaw (1980) found fair agreement between predicted and measured moisture content below 50% in the lower duff. Insensitivity of the model to duff depth variation and liquid water transport were the reasons given for poor predictability above 50% moisture content. Jarvis and Tucker (1968) found the Canadian Drought Index to be a good predictor of L and F horizon moisture content in cut-over white spruce-aspen stands (*Picea glauca* - *Populus tremuloides*). In Pacific Northwest Douglas-fir stands, good agreement was found between the NFDRS 1,000-h TL FM and lower duff moisture content, percent of duff reduction, depth of duff reduction, and mineral soil exposed by fire (Sandberg 1980).

Gravimetric moisture determination by direct fuel sampling is standard procedure for most research and some administrative fire-use projects where precision is needed. Because this method is time consuming and requires special equipment, research was conducted to test the accuracy of the National Fire-Danger Rating System moisture models, and to empirically develop equations for improved fuel moisture prediction.

Study Site

This study was conducted in conjunction with a prescribed burning project in the Santa Catalina Mountains of southeastern Arizona (Harrington 1981). The study site had a southwestern exposure with 30-50% slopes, in a stand composed primarily of ponderosa pine. Other species present were southwestern white pine (*Pinus strobiformus*), Douglas-fir, and silver leaf oak (*Quercus hypoleucoides*).

The stand consisted basically of two distinct maturity groups (fig. 1). Open groups were dominated by large, old growth ponderosa pine with a sparse pine seedling understory. These groups averaged about 600 trees per acre with 206 square feet of basal area per acre. Surface fuels were exposed to many hours of direct sunlight and direct rainfall. Closed groups were characterized by dense, overstocked clumps of ponderosa pine saplings, often referred to as "dog-hair thickets." The average density was 3,500 trees per acre with a basal area of 186 square feet per acre. With the thick canopy cover, fuels were exposed to little sunlight, and rainfall was dispersed through the canopy. Because of the obvious group differences, sampling was stratified by maturity group.

Methods

Sampling for fuel moisture determination began on June 6 and continued through August 22. Collections were made during the same time period (1300–1500 MST) each sampling date. L layer needles[2] were sampled daily because of their short response time and exposure to steep temperature and vapor pressure gradients. In addition, the following fuels were collected twice weekly: F layer needles,[3] H layer humus,[4] 0- to 0.25-inch twigs, 0.25- to 1-inch twigs, and 1- to 3-inch branchwood. Six samples of each fuel were collected from each of the two overstory groups within a 3-acre stand. Each sample was a composite of four or five subsamples. All moisture determinations were made gravimetrically.

A weather station equipped with a recording rain gage and hygrothermograph was set up on the site. Fuel moisture stick values, temperature, precipitation, and relative humidity were monitored at the Palisades fire weather station a few hundred yards from the study site.

Figure 1.—Ponderosa pine stand with two maturity groups; open group is on the right and closed group is on the left.

Results and Discussion

L Layer Moisture Content

The moisture contents of the L layer needles and H layer humus are considered the most important moisture variables in the burning of the forest floor at this site (Harrington 1981). L layer moisture content strongly influences ignitability, fire intensity, and rate of spread. H layer moisture content is a major factor in determining the amount of the forest floor which will be consumed by a fire, because more than 50% of the total loading occurred in this layer.[5] The fermentation (F) layer generally completes the moisture gradient between the L and H layers. Although the F layer moisture content has some effect on rates and amounts of forest floor consumption, its position and weight make it less influential than the surrounding layers.

Deeming et al. (1977) stated that the 1-hour timelag fuel moisture content (1-h TL FM) calculated in the 1978 NFDRS corresponds to the moisture content of cylindrical woody fuels less than 0.25-inch in diameter and of litter less than 0.25-inch deep. The latter would include the L layer needles. Comparison of calculated 1-h TL FM to actual L layer needle moisture contents from the open group is shown in figure 2.

The coefficients of determination (r^2) and standard errors ($S_{y \cdot x}$) indicate good agreement between the two variables (fig. 2). However, the relationship between the calculated 1-h TL FM and the actual L layer moisture in the open groups is not one-to-one. One reason for this is that freshly cast pine needles have a timelag of about 4 hours rather than 1 hour, and needle beds have a response time of 2.5 hours to 7 hours depending on bulk density and solar influence (Anderson

[2]*The L layer needles are the most recently fallen, unweathered, light-brown needles.*

[3]*The F layer needles are in the early stages of decomposition and weathering with a distinct grayish color.*

[4]*The H layer humus consists of fuel in advanced stages of decomposition.*

[5]*Data on file, Fuel Management Project, Tempe, Ariz.*

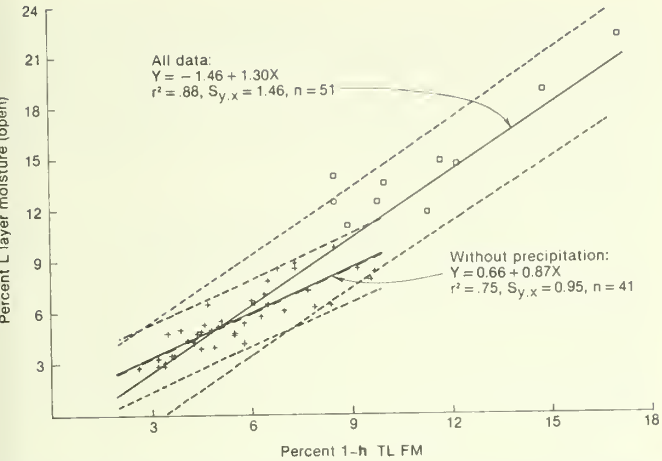

Figure 2.—Relationship of 1-h TL FM and open group L layer needle moisture with (0) and without (+) precipitation influences. Confidence bands are included, $P = 0.05$.

et al. 1978). As needles age, their timelag decreases (Simard 1968b), approaching 1 hour.

Figure 3 compares the daily trace of 1-h TL FM with open group L layer needle moisture content. The dates of four major precipitation periods are represented by the resulting high fuel moisture. When influenced by rain, the actual needle moisture content rose to higher levels than the calculated 1-h TL FM. However, the 1-h TL FM fluctuated more than actual fuel moisture when influenced by changing vapor pressure (relative humidity). This was likely a result of the greater-than-1-hour timelag of fresh needles and needle beds.

One environmental condition which caused actual and calculated fuel moisture to differ was an abrupt change in relative humidity at observation time (1300 MST), which is used to calculate 1-h TL FM (Burgan et al. 1977). Examples of this are shown in figure 4. On July 13, the humidity increased rapidly, peaked at about 0800 MST, then tapered off slowly so that at observation time it was still high (60%). The 1-h TL FM was higher than needle moisture because the latter could not respond rapidly to the abrupt humidity change. An opposite situation occurred on August 14 when a rapid decrease in humidity near observation

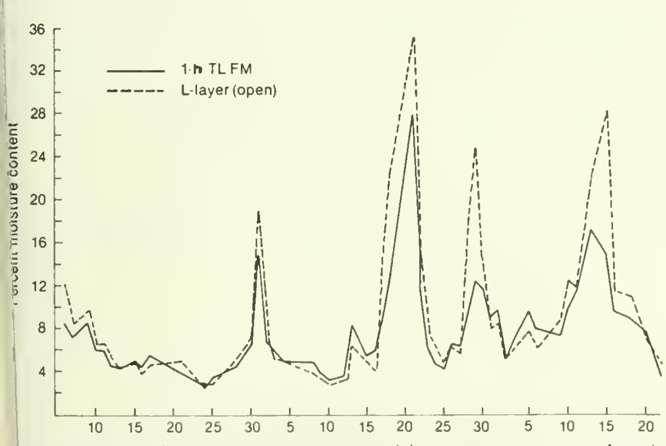

Figure 3.—A 78-day comparison of L layer needle moisture content from open groups and1-h TL FM.

time caused a lower 1-h TL FM because, again, the needle fuels do not respond to moisture changes as rapidly as air does (humidity).

Because of the complexity of the required calculations, precipitation is not part of the computations for 1-h TL FM (Fosberg and Deeming 1971). Therefore both direct and lingering effects of precipitation might cause actual fuel moisture to differ from 1-h TL FM. When the data points which represent fuel moisture influenced by precipitation within the previous 24 hours were removed, the resulting regression (fig. 2, +'s) yields a better estimator of L layer moisture in the 3% to 10% range than the regression of all points. Reasons for this are that higher moisture data are outside the critical 3% to 10% range, which contains nearly the entire fine fuel moisture range where fire will spread easily and

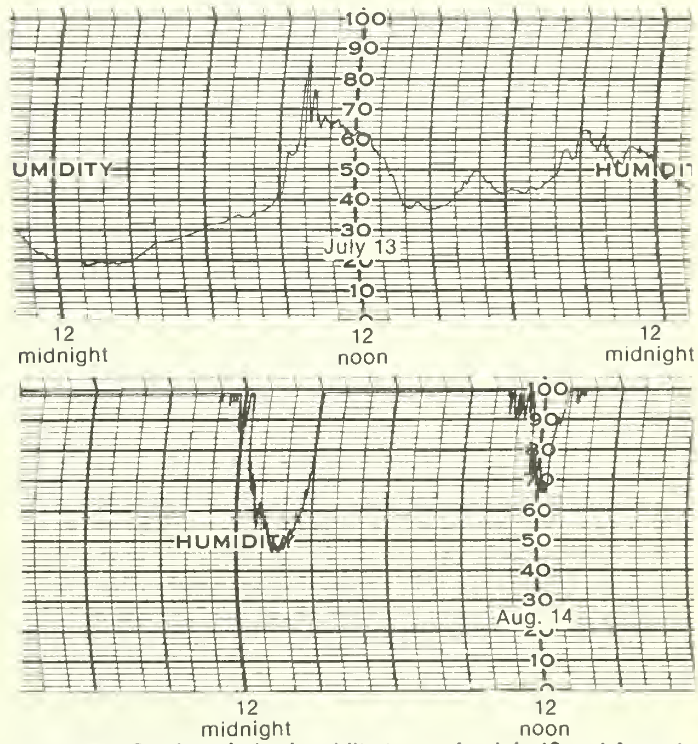

Figure 4.—On-site relative humidity traces for July 13 and August 14, 1979.

burn fuels completely; that the no-precipitation regression is less variable (narrower confidence bands); and that this regression yields an $X = Y$ relationship (i.e., tests indicate the slope approximately equals one and the Y-intercept approximately equals zero).

Agreement between 1-h TL FM and L layer needle moisture in the closed groups was also quite good (fig. 5). The slope of the regression was greater than for the open groups indicating a higher litter moisture in the closed groups for given 1-h TL FM. This was because of the constant shade, lower temperatures, and higher humidities associated with a closed stand (Simard 1968c, Countryman 1977). Removing fuel moisture points influenced by precipitation within the previous 24 hours reduced the slope of the regression and again produced a slightly better predictor of L layer moisture in the important burning range of 3% to 12%.

In the determination of fuel moisture for precribed

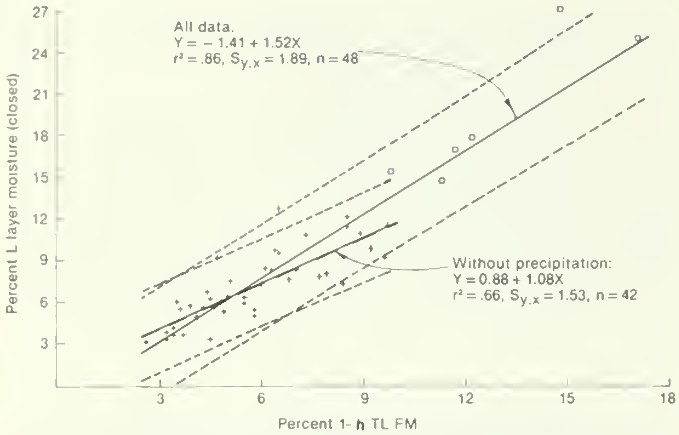

Figure 5.—Relationship of 1-h TL FM and closed group L layer needle moisture content with (0) and without (+) precipitation influences. Confidence bands are included, $P = 0.05$.

burning projects, an overestimation could result in serious consequences, such as severe fire effects or even escape fires, especially near the driest prescription limits. The regressions for both open and closed groups (figs. 2 and 5) were found to overestimate fuel moisture in situations where the 1-h TL FM was greater than the 10-h TL FM. The fuel moistures were 1% to 3% lower than predicted when this occurred.

Good agreement was found between the L layer needle moisture content of the open and closed groups. The regression equation with X being open group moisture content and Y being closed group moisture content was:

$$Y = 0.44 + 1.16X \; (r^2 = 0.92, S_{y \cdot x} = 1.41, n = 48)$$

Removing the moisture values influence by recent rainfall had little effect on the relationship:

$$Y = 0.54 + 1.15X \; (r^2 = 0.82, S_{y \cdot x} = 1.08, n = 41)$$

Because freshly cast needles and needle beds have moisture timelags greater than 1 hour, the relationship of measured L layer needle moisture with fuel stick moisture and 10-h TL FM was tested. Fuel stick moisture correlated slightly better with actual open group needle moisture (fig. 6) than did 1-h TL FM (fig. 2). Within the majority of the data range, the fuel stick moisture regression produced a one-to-one relationship between fuel stick and L layer needle moisture. This relationship did not hold for the 1-h TL FM regression utilizing the entire data range (fig. 2) because precipitation is not directly accounted for as it is with the fuel stick. Further, even though the fuel stick represents a 10-hour timelag fuel, its position above the forest floor permits it to be influenced on all surfaces by conditions of the surrounding air. The L layer is influenced by conditions of the forest floor below as well as the air above, perhaps allowing its moisture content in this range to change as does the fuel stick's. As before, when those points influenced by precipitation are removed, the new regression with narrower confidence bands becomes the preferred estimator of L layer moisture in the 3% to 10% range (fig. 6) where most prescribed and wildfires occur.

The correlation and standard error were poorer using 10-h TL FM ($r^2 = 0.81$, $S_{y \cdot x} = 1.88$) rather than fuel stick moisture ($r^2 = 0.90$, $S_{y \cdot x} = 1.33$) in the regression with L layer moisture. This suggests that the conversion of fuel stick weights to 10-h TL FM based on stick age (Burgan et al. 1977) may have overcompensated as Haines and Frost (1978) indicated.

Figure 7 shows the regression equations of closed group L layer needle moisture with both fuel stick moisture, and fuel stick moisture not influenced by rain. Again, fuel stick moisture proved to be a better indicator of needle moisture than 1-h TL FM (fig. 5). Within the 3% to 12% moisture range, the equation eliminating precipitation influence is the recommended predictor. In an attempt to develop a better moisture indicator in the canopy-covered closed groups, a new 1-h TL FM was calculated assuming a continually cloudy condition by holding the state of weather to a constant value of three (greater than 90% cloud cover). This new 1-h TL FM had a poorer correlation ($r^2 = 0.83$, $S_{y \cdot x} = 2.08$) with L layer moisture over the entire data range than either 1-h TL FM (fig. 5) or fuel stick moisture (fig. 7). However, over the moisture range not influenced by precipitation (3% to 12%), the regression equation using the new 1-h TL FM,

$$Y = 0.56 + 0.97X \; (r^2 = 0.75, S_{y \cdot x} = 1.26, n = 41)$$

had as good an agreement with L layer moisture as fuel stick moisture (fig. 7) and better than the original 1-h TL FM (fig. 5). This equation also produced a one-to-one relationship between the independent and dependent variables, as indicated by tests showing the slope approximately equals one and the Y-intercept approximately equals zero.

The best predictor of L layer fuel moisture in both groups appears to be the fuel stick. More of the variation in L layer moisture was associated with fuel stick moisture variation than with 1-h TL FM variation. Deviations from the regression were also minimized. Most burning prescriptions, such as the preliminary plan for

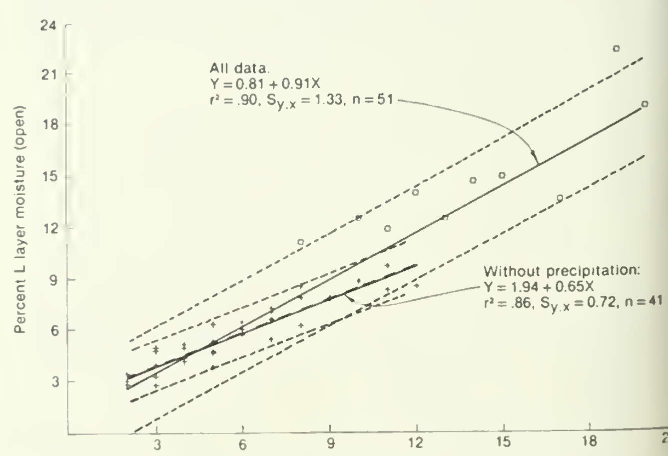

Figure 6.—Relationship of fuel stick moisture content and open group L layer needle moisture content with (0) and without (+) precipitation influences. Confidence bands are included, $P = 0.05$.

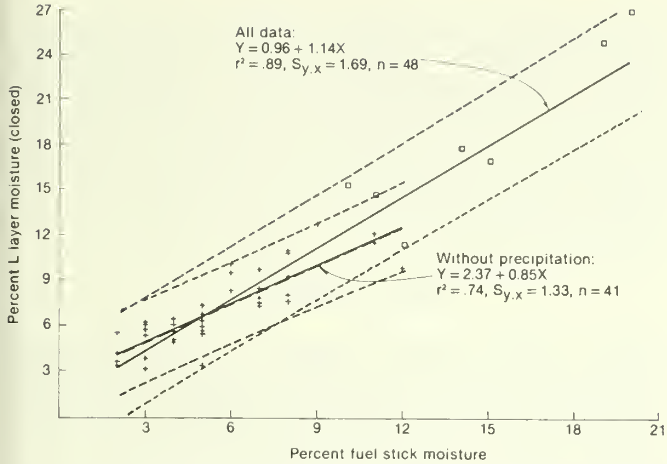

Figure 7.—Relationship of fuel stick moisture content and closed group L layer needle moisture content with (0) and without (+) precipitation influence. Confidence bands are included, $P = 0.05$.

this study site (Harrington 1981), are developed with a safety margin at each end of the moisture range. That way, even if the fuel moisture were either overestimated or underestimated, as long as other parameters were within the prescription limits, the fire should still burn safely and effectively.

H Layer Moisture Content

Deeming et al. (1977) gave representative examples of 100-hour timelag fuels as dead, roundwood fuels 1 to 3 inches in diameter and, very roughly, the forest floor from 0.75 to 4 inches below the surface. This forest floor depth would include the H layer from this study site. A regression of 100-h TL FM was made with actual H layer moisture contents taken the same day. The comparison from both open and closed groups are shown in figures 8 and 9.

There is fair agreement between the two variables in each of figures 8 and 9, but the calculated timelag moisture contents and actual fuel moisture contents fail to produce a one-to-one relationship. Possible reasons for this are:

(1) Although the humus layer may have a timelag of 100 hours under standard conditions described by Fosberg (1971), its position within the forest floor would make its response much different than if under the environmental conditions found in a weather shelter which are used in calculating 100-h TL FM. For example, the reduced evaporative potential in the lower horizons would allow a surface film of water to remain on the fuel longer and absorption to continue longer even though the upper horizons may be losing water (Simard 1968a).

(2) Because of the presence of structural water (water held between fuel particles), the moisture content of a humus layer can be more than 100%. The maximum 100-h TL FM calculated by the fire danger program presented by Burgan (1979) is 53%.

(3) Physical characteristics which influence moisture response time, such as bulk density and thickness, are certain to vary throughout the stand.

(4) Precipitation duration is used to calculate 100-h TL FM, but the lower layers of the forest floor are influenced not only by duration but also by precipitation rate (Fosberg 1971, 1979). As the rainfall rate increases, less of the water will be absorbed by the upper layers and more will pass through to the lower layers. In fact, a low-rate, short-duration rainfall will probably have no effect on the H layer other than by an increase in humidity.

As a result of these four conditions, the drying and wetting rates of the H layer humus and the calculated rates of 100-hour timelag fuels would not be equal.

Examples of these conditions are shown by the few widely dispersed data points in figure 8. All four points above and on the upper half of the regression line occurred shortly after substantial rainfall. Surface and structural water were probably present in the humus, but the 100-h TL FM was decreasing mainly because of a drop in average relative humidity. One of the two

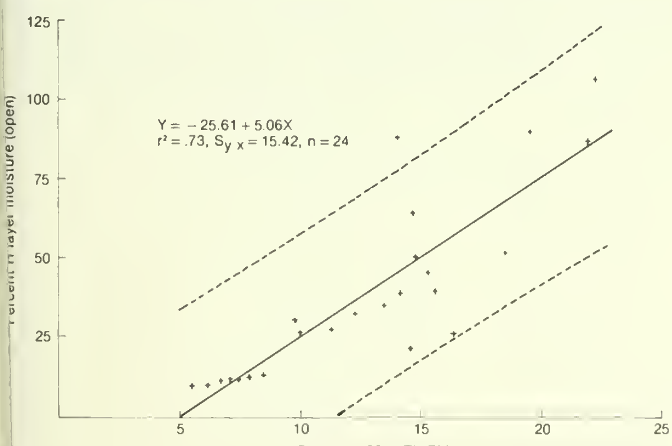

Figure 8.—Relationship of 100-h TL FM and open group H layer moisture content. Confidence bands are included, $P = 0.05$.

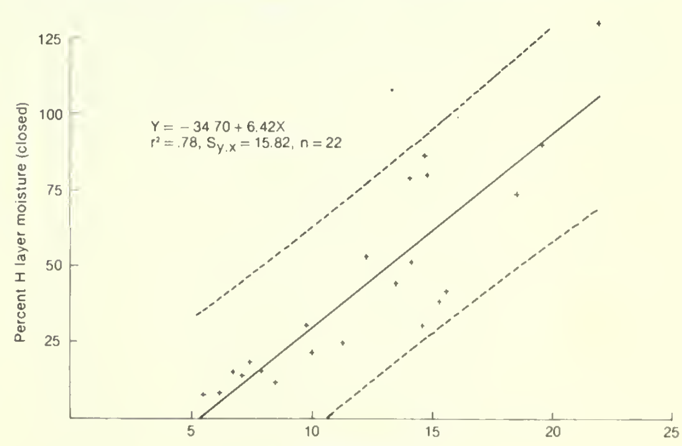

Figure 9.—Relationship of 100-h TL FM and closed group H layer moisture content. Confidence bands are included, $P = 0.05$.

data points which stand out below the regression line occurred after a rainfall of sufficient duration (4-hours) to cause an increase in the 100-h TL FM but not of sufficient quantity (0.01 inch) to reach and cause an increase in the H layer moisture content.

For precise determination of H layer moisture content using the 100-h TL FM, the equations developed here are marginally useful. For practical purposes, a rough estimate of the moisture content of this forest floor layer is all that is needed for prescribed burning. Moisture conditions which should be known are the upper limit where burning would be ineffective, the lower limit where burning would be hazardous, and, perhaps, an optimum range. These values are within the precision of the regressions and are being researched (Harrington 1981).

Moisture Content of Other Fuels

At this study site, woody fuels smaller than 3 inches in diameter make up a small portion of the total fuel loading (14%)[5] and, therefore, play a minor role in fire behavior. However, comparisons were made between the moisture contents of various size woody fuels and their corresponding calculated timelag moisture contents to test the predictability of actual fuel moisture (table 1). The F layer needles which occurred at depths of 0.50 to 1 inch should be representative of 10-hour timelag fuels (Deeming et al. 1977).

In general, the best correlations occurred between smaller fuel and shorter timelag moisture values. In each case, the regression slope was much greater than one indicating that the two variables did not have a one-to-one relationship. This lack of equality can be partially explained by the fact that the woody fuels were collected from the surface of the forest floor and, therefore, were influenced not only by the vapor pressure from the surrounding air but also from the forest floor below. In the NFDRS, fuel moisture contents are calculated from equilibrium moisture contents using weather shelter temperatures and humidities (Fosberg and Deeming 1971). Therefore, an aerial fuel situation is assumed. Also, the actual fuel moisture changed to a greater extent with precipitation than did the corresponding timelag fuel moisture. As in the regressions for estimating L layer needle moisture content, relationships between calculated and actual moisture contents were closer to unity when moisture values for fuels recently influenced by precipitation were removed.

Table 1.—Regressions comparing actual fuel moisture (*Y*) with corresponding timelag fuel moisture calculated from the National Fire-Danger Rating System (*X*)

Fuel	Timelag	Regression	r^2	$S_{y \cdot x}$	n
F layer needles (open)	10-hour	$Y = -16.04 + 3.73X$	0.74	13.81	22
F layer needles (closed)	10-hour	$Y = -19.05 + 5.00X$	.71	19.95	22
0- to 1/4-inch wood (open)	1-hour	$Y = -2.79 + 1.88X$	.89	2.71	20
0- to 1/4-inch wood (closed)	1-hour	$Y = -5.83 + 2.80X$	.86	4.60	20
1/4- to 1-inch wood (open)	10-hour	$Y = -16.44 + 3.55X$	.86	7.65	22
1/4- to 1-inch wood (closed)	10-hour	$Y = -17.02 + 4.00X$	.85	10.30	22
1- to 3-inch wood (open)	100-hour	$Y = -36.01 + 4.87X$	.62	19.15	24
1- to 3-inch wood (closed)	100-hour	$Y = -29.67 + 4.39X$	.65	15.83	24

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Comparisons were made between moisture contents of natural ponderosa pine fuels and the corresponding timelag moisture values calculated using the National Fire-Danger Rating System. The two variables correlated well at the driest moisture levels, but precipitation influenced each differently. Empirically derived equations permit adequate estimates of actual fuel moisture for burning projects.

Keywords: Fuel moisture content, National Fire-Danger Rating System, *Pinus ponderosa* var. *arizonica*

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

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Fort Collins,
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Research Paper
RM-234

Cord, Volume, and Weight Relationships for Small Ponderosa Pine Trees in the Black Hills

Donald C. Markstrom, Dennis M. Donnelly, Janet L. Van Glarik, Richard O. Woodfin, Jr., and Harold E. Worth

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June 1982

Cord, Volume, and Weight Relationships for Small Ponderosa Pine Trees in the Black Hills[1]

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Abstract

Wood volume and oven-dry weight of wood and of bark can be reliably estimated from the combined green weight of wood and bark, with 97% of the variation being accounted for in predicting wood volume (cubic feet), 99% in predicting oven-dry weight of wood, and 91% in predicting oven-dry weight of bark. Simulation of random truckloads of small roundwood show that this class of material can be weight scaled by either ratio weight or regression weight-scaling methods based on a small number of sample loads. The average wood volume in sample cords was 72.8 cubic feet, for bolts from 5-7 inch trees, with a coefficient of variation of 3.2%.

[1]This research was conducted jointly by the Rocky Mountain and Pacific Northwest Forest and Range Experiment Stations, with assistance from the Black Hills National Forest.
[2]Headquarters is in Fort Collins, in cooperation with Colorado State University.
[3]Headquarters is in Portland, Oregon.

Cord, Volume, and Weight Relationships for Small Ponderosa Pine Trees in the Black Hills

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Management Implications

Timber below sawtimber size is commonly harvested in commercial thinning, pulpwood, or multiproduct sales. It is typically marketed as pulpwood or, increasingly, as firewood. There is also interest in this class of timber as raw material for structural flakeboard. For each of these purposes, the most important characteristic of the trees is the amount of wood substance they contain when dry. Because the amount of dry wood substance in a standard cord varies with the diameters of the bolts in the cord, the cord is not a very exact unit of measure. A cord comprised of bolts with a larger average diameter contains more dry wood substance than one with bolts of smaller average diameter.

The logical alternatives to cord measurement are bolt-volume scaling and weight scaling. Volume scaling has the advantage of measuring the wood substance in each bolt directly with a high degree of precision. Its disadvantages are the time it takes and the cost. Weight scaling, while potentially less accurate, is fast and relatively inexpensive.

Almost 500 small ponderosa pine trees (below sawtimber size) were sampled at 10 sites, in the Black Hills National Forest, to determine the relationships between standard cord volume (128 cubic feet) actual volume of the wood, and dry weight of the wood. The volume of wood in a standard cord in this size class did not vary much, averaging 72.8 cubic feet of green wood. The weight of green cordwood was shown to be a reliable indicator of wood volume. These research results should help buyers and sellers of small roundwood to decide which of these systems is most cost effective for their purposes.

Introduction

Most ponderosa pine (*Pinus ponderosa*) small roundwood in the Black Hills has been marketed for pulpwood and post material on a cord basis. This method, while convenient, has led to disputes between some buyers and sellers about the actual volume of solid wood in a cord, which is the bulk volume of a stack of cordwood 4 feet by 4 feet by 8 feet. Important factors affecting the solid wood volume in a cord include bolt diameter, bark thickness, and bolt straightness. Defect deductions are occasionally made for fire scar and crook, depending upon severity and extent. Rot generally is not severe enough in these size trees to warrant a deduction.

A structural flakeboard manufacturing facility has been proposed for the Black Hills (Black Hills National Forest Product News 1980). Reportedly, this plant could increase the demand for small roundwood annually by as much as 100 thousand cords. Development of weight-scaling procedures based on this research might reduce the cost of sales administration if such a plant were built.

Myers (1960) reported research on volume-weight-moisture relationships for ponderosa pine in the Black Hills. He found that the oven-dry weight of the merchantable boles of trees from 6 to 11.5 inches d.b.h. was closely correlated with their cubic foot volumes. There was no significant difference in the density (dry weight per cubic foot) of trees from thinned and unthinned stands nor any correlation between wood density and the following variables: form quotient, age on stump, crown class, crown diameter, crown length, percent of tree length in crown, site index, and stand basal area. The average specific gravity and density were 0.393 and 24.5 pounds per cubic foot, respectively.

Landt and Woodfin (1959) reported that the specific gravity for trees younger than 100 years, in the Black Hills, averaged 0.398; specific gravity for older trees averaged 0.417. The younger trees had a greater green weight per cubic foot because of higher moisture content. The younger trees also had a higher proportion of sapwood. An average cord sampled from trees ranging from 6 to 12.9 inches d.b.h. contained 75.9 cubic feet of wood. Other research in the Black Hills showed that wood specific gravity decreased with increasing height up the merchantable stem (Markstrom and Yerkes 1972).

Yerkes (1966) developed regression formulas to predict the density of ponderosa pine sawlogs. The important variables included diameter inside the bark (d.i.b.) of the small end and average moisture content. Formulas to predict net cubic-foot volume of green ponderosa pine logs included total log weight, log diameter inside the bark at the small end, and percent defect.

Donnelly and Barger (1977) evaluated three weight-scaling methods—sample-stick, ratio-weight, and regression-weight scaling—for southwestern ponderosa pine timber. Regression-weight scaling was found to be more precise than the other two. The most precise regression equation that was practical to apply included net load weight and log count. However, other factors that must be considered are sales area, seasonal changes in moisture content, log length mix, and the young-growth/old-growth mix.

Much additional weight-scaling research has been reported in the literature, largely for southern pine and hardwood sawlogs, veneer logs, and pulpwood (Blair 1965, Fasick et al. 1974, Guttenberg and Fasick 1973, Guttenberg et al. 1960, Row and Fasick 1966, Row and Guttenberg 1966, Schumacher 1946, Taras 1956, Tyre et al. 1973, Weldon 1967, Wensel 1974). Lothner et al. (1974) reported the weight per unit volume for aspen pulpwood during the summer and winter in northern Minnesota.

Study Objectives

The overall objectives of this study were to develop information about volume-weight-moisture relationships of the trees that would be useful in weight scaling small roundwood and to determine methods that might be used to estimate truckload cubic volumes based on truckload weights.

Specific objectives were to:

1. Determine the effects of tree diameter and sampling area on:
   a. green weight of wood and bark per cubic foot of wood,
   b. moisture content of the wood, and
   c. moisture content of the bark.
2. Develop regression equations to predict the volume of wood, oven-dry weight of wood, and oven-dry weight of bark of the trees based on the green weight of the wood and bark.
3. Determine the actual volume of wood in a standard 128-cubic-foot cord.
4. Determine the effect of size of truckload upon the ratio weights and the regression-weight equations.
5. Determine the effect of number of truckloads upon the ratio weights and the regression-weight equations.

A ratio weight or cubic volume of wood per unit weight of wood and bark is actually a form of a simple linear regression equation where the constant term is zero.

Study Area and Methods

A total of 489 live trees were sampled on 10 plots throughout the Black Hills National Forest (fig. 1). These plots were selected to be representative of those to be harvested throughout the Black Hills. The sample trees on each plot were selected as to stem characteristics to benefit future sawtimber production. Three percent had either forked or dead tops. Approximately equal numbers of trees were sampled at each site in the 5-, 6-, and 7-inch d.b.h. classes. Ninety-six percent of the trees contained at least two 100-inch pulp bolts with a minimum d.i.b. of 3-1/2 inches. The other 4% contained at least one full bolt. Characteristics of the sample trees are shown in table 1.

The field procedure was to measure diameter at breast height, fell, and buck-selected trees into 100-inch bolts and a short bolt, if necessary, to include the 3-1/2 inch top d.i.b. Total height, height to 4-inch top d.i.b., diameter inside bark at the end of each bolt, length of the short bolt, and weight of each bolt were measured immediately after felling each tree. The tree volumes were calculated from the bolts using Smalian's formula, and assuming: (1) utilization to a 3-1/2 inch top d.i.b. and (2) utilization of 100-inch bolts only. All of the 100-inch bolts for each plot were stacked in a portable rick to estimate cord volume immediately after weighing (fig. 2). The number of cords per plot ranged from 2.01 to 2.90.

Sixty of the above trees—two randomly selected within each diameter class at each site—had 1-inch-thick disks cut at 100-inch intervals from stump height to 3-1/2 inches d.i.b. Age was determined from the disk taken from approximately 1 foot above ground and growth rate from the disk taken at approximately 9 feet above ground. The bark and wood of each disk, after being separated and weighed, were oven-dried at 103° C for 24 hours and were reweighed. The bark and moisture content values of each disk were calculated and then weighted by disk diameter to reflect a single value for each tree.

The green weight of wood and bark per cubic foot of wood for the tree was calculated by adding the weights of all bolts (to the 3-1/2 inch d.i.b. top) and dividing by the cubic volume. Tree specific gravity was calculated as follows:

$$SG = \frac{(A)\ (B)\ (100)}{(C + 100)\ (D)}$$

where

SG = specific gravity of the tree
A = green weight of wood and bark per cubic foot of wood
B = proportion of green wood to total green wood and bark by weight
C = percent moisture content of wood based on oven-dry weight
D = weight per cubic foot of water: 62.4 pounds.

Table 1.—Characteristics of sample trees

Tree characteristics	Mean ± SD	Number of trees
Diameter (inches d.b.h.)	6.5 ± 0.8	489
Total height (feet)	42.8 ± 7.9	489
Height to 3½ inch top d.i.b. (feet)	27.8 ± 7.6	489
Volume to 3½ inch top d.i.b. (cubic feet)	3.90 ± 1.61	489
Volume, utilizing 100-inch bolts only (cubic feet)	3.57 ± 1.60	489
No. of 100-inch bolts per tree	2.9 ± 0.9	489
Age at stump (years)	82 ± 9	60
Increment growth rate (rings per inch)	26 ± 4	60
Percent bark, green weight basis	12.4 ± 1.4	60
Percent bark, oven-dry weight basis	17.2 ± 2.1	60
Specific gravity of wood	0.395 ± 0.029	60

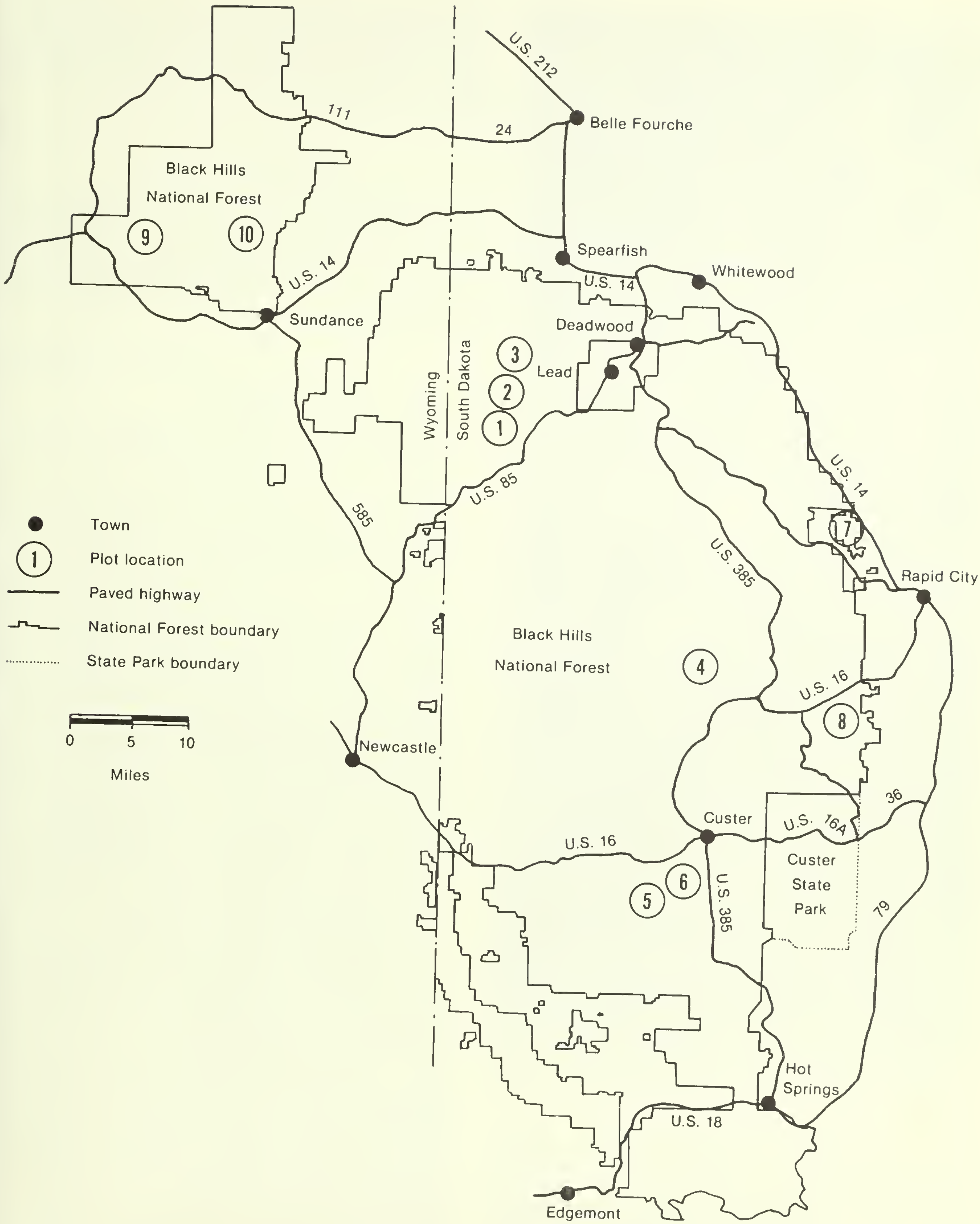

Figure 1.—Study trees were selected from 10 sampling plots in the Black Hills of South Dakota and Wyoming.

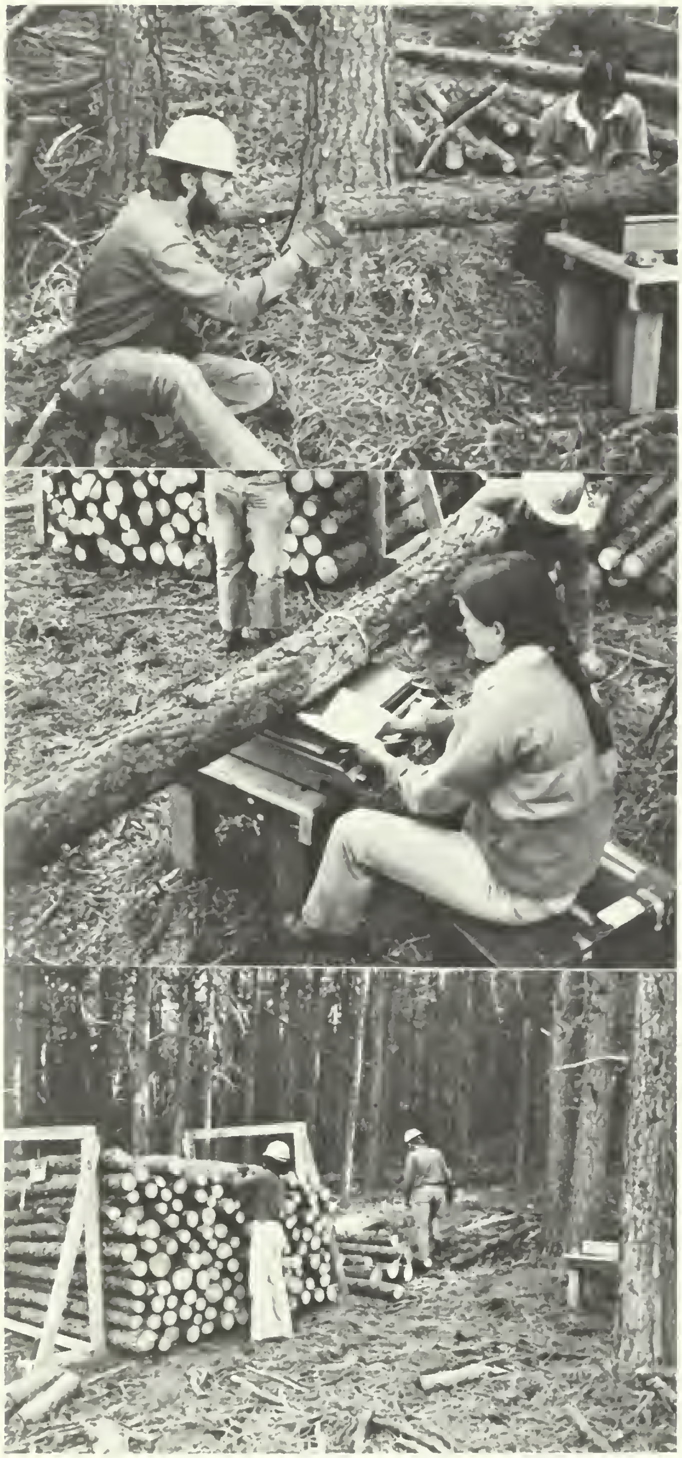

Figure 2.—All bolts were measured for diameter inside bark and length and weighed. The 100-inch bolts were placed in a rick to determine cord volume.

Three characteristics of the trees that are important for weight scaling are (1) green weight of the wood and bark per cubic foot of wood, (2) percent moisture content of the bark, and (3) percent moisture content of the wood. Each of these were analyzed factorially to determine the effect of tree diameter, general sampling areas, and plot locations within each sampling area.

Four general sampling areas—northern, central, and southern Black Hills and the Bearlodge Mountains—were classified to reflect both possible variations among plot locations and existing industry production and marketing patterns for small roundwood.

Results and Discussion

The factorial analyses indicated that tree diameter and sampling area did not significantly affect either the green weight of wood and bark per cubic foot of wood or the moisture contents of the bark and wood. The overall means and standard deviations for these tree characteristics were:

	Mean ± SD	Number of trees
Green weight of wood and bark per cubic foot of wood (pounds per cubic foot)	64.6 ± 4.4	489
Moisture content of wood (percent of oven-dry weight)	132 ± 13	60
Moisture content of bark (percent of oven-dry weight)	64 ± 14	60

However, factorial analyses did indicate that plot location within the sampling areas did significantly affect the above characteristics. The variation between and within plots of each sampling area is shown by the plot means and standard deviations (table 2). The practical effect of plot location within sampling area may be interpreted by comparing the dollar value of a green ton of wood and bark from two plots in the northern sampling area. One ton of wood and bark would contain from 30.0 to 31.8 cubic feet of wood, based on green weight of wood and bark ranging from 66.6 to 63.0 pounds per cubic foot. The corresponding values per green ton of wood and bark would range from \$12.60 to \$13.36, assuming the wood to be worth \$42.00 per cunit delivered to a plant site.

The possibility was recognized that some site-related factors not measured in this study could affect both green weight and the moisture content. Yerkes (1967) found that ponderosa pine trees on a north slope and a well-drained flat averaged from 8% to 14% higher moisture content than those on a ridgetop, a south slope, and a beaver-pond fill. Variation in specific gravity with site is another possibility. However, the average specific gravity of 0.395 for the wood of the trees in this study was similar to 0.398 determined by Landt and Woodfin (1959) and 0.393 by Myers (1960) for Black Hills ponderosa pine.

Equations to predict cubic volume and oven-dry weight of wood and oven-dry weight of bark of the trees were developed and evaluated in conjunction with the previous analyses of variance, as follows:

Table 2.—Green weight of wood and bark (pounds) per cubic foot of green wood and the moisture content of the wood and bark (percent of oven-dry weight) for each plot

Sampling area	Plot number	Green weight of wood and bark per cu ft of green wood	Moisture content	
			Wood	Bark
		M ± SD		
Northern	1	66.6 ± 3.5	138 ± 10	75 ± 10
	2	63.0 ± 4.6	127 ± 12	67 ± 10
	3	65.9 ± 4.4	132 ± 11	66 ± 19
Central	4	63.8 ± 4.5	140 ± 8	68 ± 9
	7	65.4 ± 4.3	125 ± 11	45 ± 6
	8	65.9 ± 3.1	126 ± 13	48 ± 9
Southern	5	62.2 ± 3.9	119 ± 17	62 ± 13
	6	64.0 ± 4.3	145 ± 10	69 ± 12
Bearlodge	9	64.6 ± 4.7	127 ± 6	63 ± 7
	10	65.0 ± 4.8	140 ± 6	73 ± 14

	$S_{y \cdot x}$	R^2	n	
For volume of wood (cubic feet)				
$Y_1 = \underset{(0.030)}{0.182} + \underset{(0.0001)}{0.015X_1}$	0.261	0.97	489	[1]
For oven-dry weight of wood				
$Y_2 = -\underset{(1.666)}{0.635} + \underset{(0.006)}{0.382X_1}$	5.543	0.99	60	[2]
For oven-dry weight of bark				
$Y_3 = \underset{(0.757)}{2.369} + \underset{(0.003)}{0.065X_1}$	2.518	0.91	60	[3]

Where:

Y_1 = wood volume (cubic feet)
Y_2 = oven-dry weight of wood (pounds)
Y_3 = oven-dry weight of bark (pounds)
X_1 = total green tree weight of wood and bark (pounds)
$S_{y \cdot x}$ = standard deviation of wood volumes or oven-dry weights about the regression
R^2 = coefficient of determination
n = number trees

The values in parenthesis under each coefficient are the respective standard errors.

The combined green weight of wood and bark was the single variable that best predicted the cubic volume of wood and the oven-dry weights of wood and bark in the tree. The addition of diameter at breast height did not substantially improve the prediction. Plotting of residual values (difference between predicted and actual values) for each sampling area indicated that the prediction formula consistently fitted the data. Figures 3, 4, and 5 show the regression line and the 95% confidence intervals of the single tree values predicted from the total weight of wood and bark.

The volume of wood per cord sampled from the 10 plots was 72.8 ± 2.3 cubic feet (average ± 1 standard deviation). The corresponding green weight per cord was 4,676 ± 151 pounds. These averages are less than the 75.9 cubic feet and 4,950 pounds per cord reported by Landt and Woodfin (1959). The lower values per cord and small variances in the present study may be partially attributed to the smaller trees sampled.

The preceding regression equations and green weight per cord were based on trees sampled at one time of the year—in September. Seasonal variation in tree water content has been reported and possibly could affect the regression equation and the green weight per cord (Yerkes 1967).

Truckload Simulation

The purpose of the truckload simulation was to provide a first estimate of statistical values necessary for implementing truckload weight scaling of small roundwood. The simulations were based on present industry practice of either cutting small roundwood trees into 100-inch bolts and hauling them to a rail siding for shipment to distant pulpmills or cutting the trees into tree length logs and hauling them to a local processing plant. Consequently, loads were simulated that contained trees only and that contained bolts only. Tree loads were made up of 100-inch bolts and bolts less than 100 inches so that simulated tree-length logs extended to a 3.4-inch top d.i.b. Bolt loads contained only 100-inch bolts, with each full bolt in a tree considered as an individual member of the population.

The load weight classes ranged from 5,000 pounds to 70,000 pounds at 5,000-pound intervals, with 25 loads and 50 loads simulated for each weight class. The weight classes were chosen to represent a range of load sizes that may be hauled in the Black Hills.

A uniform distribution random number generator was used to select trees or bolts to be included in a load to produce an equal likelihood of choosing any one of the 489 trees or 1,311 bolts. The last tree or bolt added to a load brought the weight to just at or above the appropriate weight class. Only results from the 25-load simulations are reported in this paper, because the results from the 25-load and 50-load simulations were similar.

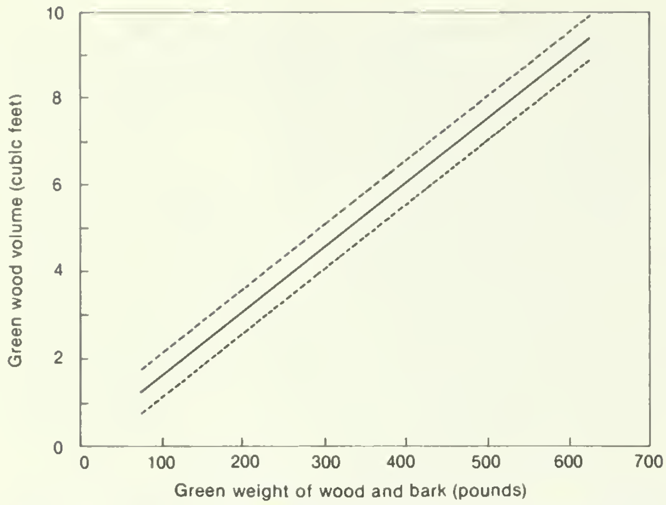

Figure 3.—Green wood volume of tree predicted from green weight of wood and bark, with 95% confidence interval of single tree values about linear regression line.

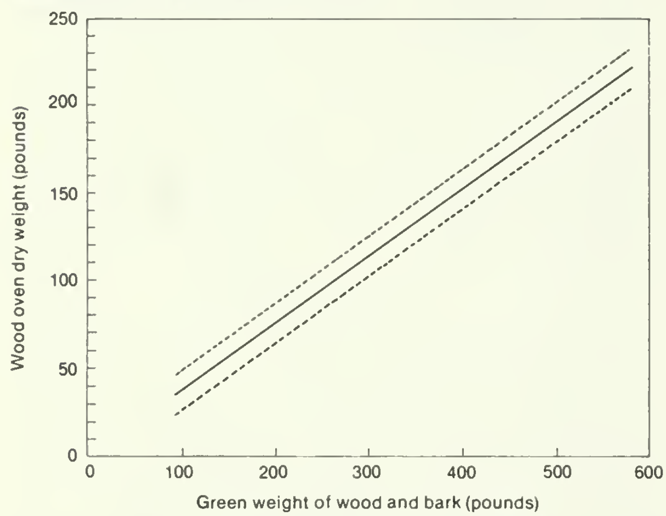

Figure 4.—Oven-dry weight of wood from tree predicted from green weight of wood and bark, with 95% confidence interval of single tree values about linear regression line.

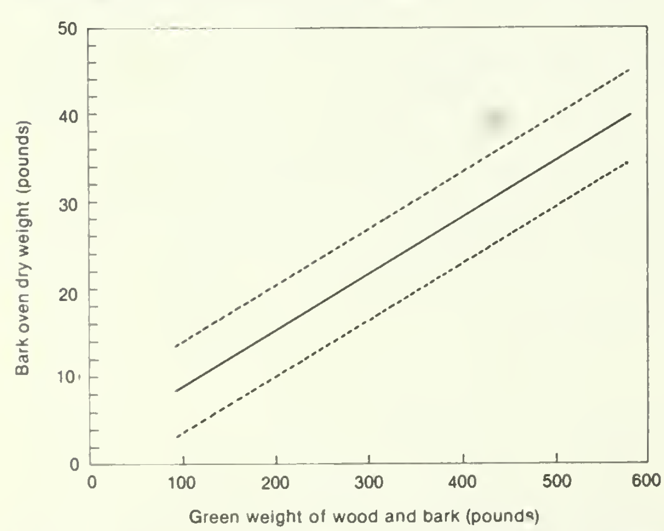

Figure 5.—Oven-dry weight of bark from tree predicted from green weight of wood and bark, with 95% confidence interval of single tree values about linear regression line.

Ratio Weight Scaling

One objective of simulating loads of different weights was to determine the effect of load size upon the ratio weight or cubic feet of green wood per 100 pounds of green wood and bark. The mean and standard deviation of the ratio weights for the individual 489 trees and 1,311 bolts were 1.555 ± 0.111 and 1.546 ± 0.163. The means of the ratio weights for the truckloads of trees and bolts are similar to those of the individual trees and bolts, but the standard deviations for the truck loads are considerably less than those for the individual trees and bolts because of measuring variability of aggregated quantities (table 3).

Cubic-foot volumes for truckloads with different weights of trees and bolts were estimated using a mean ratio weight of 1.543 cubic feet per 100 pounds for tree loads and 1.555 for bolt loads. Simulated weights are at 25 loads per weight class.

Truckload weight	Volume of green wood	
	Trees	Bolts
— *pounds* —	— *cubic feet* —	
5,000	77.1	77.8
10,000	154.2	155.5
15,000	231.3	233.3
20,000	308.4	311.0
25,000	385.5	388.8
30,000	462.6	466.5
35,000	539.7	544.3
40,000	616.8	622.0
45,000	693.9	699.8
50,000	771.0	777.5
55,000	848.1	855.3
60,000	925.2	933.0
65,000	1,002.3	1,010.8
70,000	1,079.4	1,088.5

Regression Weight Scaling

The following two equations for predicting the cubic volume of wood from the green weight of the wood and bark were developed. Equation [4] is based on samples of trees. Equation [5] is based on samples of bolts. The simulation included 25 loads per weight class.

Equation	$S_{y \cdot x}$	R^2	
$Y_1 = \underset{(0.371)}{0.279} + \underset{(0.0009)}{1.542X_1}$	3.272	0.99	[4]
$Y_2 = \underset{(0.330)}{0.199} + \underset{(0.0008)}{1.554X_1}$	2.917	0.99	[5]

Where:

X_1 = green weight of wood and bark in 100-pound units
Y_1 = cubic feet of wood (trees)
Y_2 = cubic feet of wood (bolts)
$S_{y \cdot x}$ = standard deviation of wood volume about the regression
R^2 = coefficient of determination

Table 3.—Summary of ratio weights (cubic feet per 100 pounds)[1]

Simulated truckloads of trees or bolts	Ratio weights per truckload			
	Means		Standard deviations	
	Range	Average	Range	Average
Trees	1.540-1.546	1.543	0.006-0.029	0.013
Bolts	1.553-1.557	1.555	0.006-0.022	0.011

[1]*Calculated by simulating 25 truckloads of trees and bolts at 5,000-pound intervals from 5,000 to 70,000 pounds total load weight.*

The values in parenthesis under each coefficient are the respective standard errors.

The two equations are nearly identical and predict similar truckload volumes. The high R^2 values attest to the goodness of fit of the regression. The constant term for each of the equations is not statistically different from zero ($P = 0.05$). Consequently, ratio-weight scaling can be used.

Application

Truckload simulation has indicated low variation in the ratio weights and the regression equations predicting cubic volume of wood from the green weight of wood and bark. Calculation of sample size in the following example indicated that only 6 truckloads in a 500-load sale need to be sampled by the ratio weight-scaling method to remain within a 2% allowable error at the 95% confidence level. The small number of sample loads required may be attributed to the uniformity of the trees in the diameter at breast height classes sampled and the narrow range of diameter at breast height sampled. A larger sample size would likely be needed for a field situation in which a wider range of diameter at breast height would be encountered in the trees to be utilized.

The number of sample loads required for a given sale can be approximated at the start of the sale using a coefficient of variation developed from data in this report. The number of sample loads should be recalculated based on sale data after a representative number of loads have been sampled. The number of truckloads required in the sample can be calculated as follows:

$$n = \frac{1}{\left(\frac{PE}{CV}\right)^2 \left(\frac{1}{t^2}\right) + \frac{1}{N}} \qquad [6]$$

where ·

n = number of truckloads in the sample
N = estimated total number of loads in sale
PE = $(E/\bar{x}) \times 100\%$
CV = $S/\bar{x}$
$\bar{x}$ = mean of ratio estimator in cubic feet of wood per 100 pounds of wood and bark
t = Student's t value; for n larger than 25, $t \cong 2$
E = one-half the width of the desired confidence interval; that is, the precision for the sample estimate of the mean in cubic feet of wood per 100 pounds of wood and bark
S = estimate of standard deviation of the ratio estimation of the population in cubic feet of wood per 100 pounds of wood and bark.

The following steps illustrate the computation of sample size with examples:

1. Estimate the average truckload ratio weight in cubic feet of wood per 100 pounds of wood and bark from experience or a presale sample.

   $\bar{x}$ = average truckload ratio weight
   = 1.540 cubic feet per 100 pounds (table 3).

2. Estimate truckload ratio weight standard deviation from experience or a presale sample.

   S = truckload standard deviation
   = 0.029 cubic feet per 100 pounds (table 3).

3. Compute estimated percent coefficient of variation by dividing S by $\bar{x}$.

$$CV = \frac{S}{\bar{x}} \times 100\% = \frac{0.029}{1.540} \times 100\% = 1.88\%$$

4. Decide on allowable percent error in sale estimate. Normally, this would be 2%, 3%, or 4%.

$$PE = 2\%$$

5. Estimate total number of truckloads in the sale (N) from estimated total sale cruise volume and estimated average load size. If estimated total cruise volume on sale equals 360,000 cubic feet and average load size equals 720 cubic feet,

$$N = \frac{360{,}000}{720} = 500 \text{ loads}$$

6. Substituting the above quantities and determining the proper t value through trial and error, the number of truckloads to sample (n) was calculated as follows:

$$n = \frac{1}{\left(\frac{2}{1.88}\right)^2 \left(\frac{1}{(2.571)_2}\right) + \frac{1}{500}} = 5.77$$

The minimum sample size using the next higher whole number is 6.

The allowable error of 2% signifies the following in terms of dollars to the buyers and sellers: truckloads containing 46,750 pounds of green wood and bark would average 720 cubic feet in the application example; the actual volume of wood on these truckloads would range from 705.6 to 734.4 cubic feet, assuming a 2% allowable error at the 95% confidence level; the value of the wood per truckload based on ratio weight scaling would be $302.40, assuming wood to be worth $42.00 per cunit; the values of the same truckloads based on cubic volume measurements could range from $296.35 to $308.45.

Conclusions

The results of this study indicate that cubic feet volume and oven-dry weight of wood and oven-dry weight of bark can be estimated from the combined green weight of the bark and wood. Green weight alone accounted for 97% of the variability (coefficient of determination) in predicting cubic volume of wood, 99% in predicting the oven-dry weight of wood, and 91% in predicting the oven-dry weight of bark.

Simulated truckloads of roundwood from 5- to 7-inch d.b.h. trees indicated that this material could be weight scaled with relatively few sample loads from a timber-sale area. However, the ratio weights and regression equations given in this report apply only to the study samples. Before they are used for other samples they must be checked against actual loads. The trees included in a sale may have a wider range in diameter at breast height than those in this study. Because seasonal variation in tree-moisture content and possible site source of variation could affect weight scaling (Yerkes 1967), periodic sampling to verify or recalculate ratio weights or regression equations for a sale is necessary. Data from this report may be used to approximate the number of sample loads required at the start of a sale. The number of sample loads should be recalculated when actual sales data become available.

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Wood volume and oven-dry weight of wood and of bark can be reliably estimated from the combined green weight of wood and bark, with 97% of the variation being accounted for in predicting wood volume (cubic feet), 99% in predicting oven-dry weight of wood, and 91% in predicting oven-dry weight of bark. Simulation of random truckloads of small roundwood show that this class of material can be weight scaled by either ratio weight or regression weight-scaling methods based on a small number of sample loads. The average wood volume in sample cords was 72.8 cubic feet, for bolts from 5-7 inch trees, with a coefficient of variation of 3.2%.

Keywords: Small roundwood, weight scaling, volume scaling, *Pinus ponderosa*, cords, cubic feet, truckload scale, pulpwood

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

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