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Habitat Mapping and Interpretation in New England

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Abstract

Recommendations are given on the classification of forest land in New England on the basis of physiographic region, climate (elevation, latitude), mineralogy, and habitat. A habitat map for the Bartlett Experimental Forest in New Hampshire is presented based on land form, vegetation, and soil materials. For each habitat or group of habitats, data are presented on stand composition, understory vegetation, biomass, volume, and diameter development by species.

In this paper I describe methodology and approaches for the classification and mapping of forest habitats in New England. Then, I give an example of habitat mapping on the Bartlett Experimental Forest in central New Hampshire with interpretations on species composition, productivity, and silvicultural approaches.

Classification Approaches

Many forest land-classification systems have been described for the United States and Canada, and other parts of the world. Bailey and others (1978) emphasize the distinction between taxonomic or place-independent classifications and place-dependent classifications. Taxonomic classifications are systems for grouping objects into homogeneous classes without regard for their geographic affinities. Place-dependent classifications are designed to subdivide existing landscapes into homogeneous geographic units. These systems are designed to segregate forest land into parcels with distinct characteristics or use potentials. I'll discuss four different approaches to classifying forest land:

1. Biological
2. Physical/chemical
3. Production-oriented
4. Biophysical

Biological approaches emphasize natural associations of flora or fauna. Typical examples are the habitat types of Pfister and Arno (1980) or Daubenmire (1952) and the ground vegetation types of Westveld (1951). Maps of major forest regions and cover types (Society of American Foresters 1980) also fall within this category. The biological approach to forest land classification employs the concept that natural associations of plants or animals reflect or integrate the important factors that affect forest use and production.

Physical/chemical approaches depend upon the classification of nonliving factors of the environment. Soil classifications are taxonomic systems falling within this category. Approaches based primarily upon elevation (Bormann et al. 1970) or landform are integrated (taxonomic and place-dependent) systems of the physical/chemical type. This approach assumes that nonliving factors influencing forest use and protection can be determined, measured, and mapped. The approach does not depend upon the availability of suitable, existing vegetation—an advantage in heavily disturbed areas.

Production-oriented approaches are taxonomic systems that relate directly to the land's capacity to produce certain products. These are sometimes referred to as technical or artificial classifications (Bailey et al. 1978). Classifications of areas by average site index, merchantable height, or volume are examples of the production-oriented approach. Within this category I also include methods based on indirect estimates of productivity, for example, regression equations that predict site index. Production-oriented approaches often are closely related to the interests and needs of practicing foresters.

Biophysical approaches are integrated systems where the units are classified by both biological and physical/chemical criteria. The holistic system of Hills (1953) is a pioneering example. The habitat types described by Mueller-Dombois (1965) on the basis of tree-shrub vegetation, soils, and glacial deposit also typify the biophysical approach. The approach is based upon the concept that biological and physical/chemical conditions can be correlated on the ground so that all criteria will share common boundaries. If this can be done successfully, biophysical schemes provide a fairly broad base for evaluating resource use and protection.

Forest land systems are classified in other ways as well. Many systems are hierarchical to some degree. This means that they allow for the definition of large, general units useful for broad planning purposes as well as smaller, more homogeneous subdivisions useful for conducting project work. Some systems are based on single factors; others are multifactor classifications (Bailey et al. 1978). Within the multifactor category, some factors may be considered as criteria necessary for the classification of units, and others may be given less weight as associated characteristics.

The habitat classification described in this paper is a biophysical scheme. Vegetation within New England varies, first of all, because of climate; we see obvious differences in species mixes in northern and southern New England, along the seacoast, in the high elevation zones, and so on. Next, we find differences in vegetation because of the mineralogy of the glacial drift: granite versus schist versus limestone, for example. Finally, within areas of similar climate and mineralogy, vegetation varies between habitats defined primarily by parent soil materials or glacial process.

So a habitat is a small unit of land from a few to over 100 acres lying within a given climatic-mineralogical zone and supporting a distinct successional sequence of vegetation growing on a unique type of soil material. Habitats also are associated with certain landforms, surface conditions, and types of ground flora; these characteristics are useful in mapping. Habitats, thus defined, reflect productivity in terms of species combinations and growth rates, as well as certain management limitations such as windthrow and machine operability. Diagramatically, the system may be represented as:

Climatic regions (geographic subdivision)
↓
Mineralogy (taxonomic subdivision)
↓
Habitats (taxonomic sites having characteristic soils, landforms and chronosequences of vegetation)

Climatic-mineralogical Zones

A detailed classification of the important climatic-mineralogical zones in New England and adjacent states is impossible at this time. However, available information indicates that the region might be subdivided on the basis of physiographic zones, elevation, latitude, and broad mineralogical classes.

Physiographic Regions

Lull (1968) published physiographic regions (Fig. 1) adapted from Fenneman (1938) for New England and adjacent states. These physiographic regions are based on broad differences in relief or geomorphology, climate, and proximity to water bodies and, thus, represent a reasonable starting point for segregating and studying the forest vegetation. These physiographic regions correlate to some extent with the major forest regions (Fig. 2) published by Lull (1968). But the correlations are limited because most of the physiographic regions cover a broad range in elevation or latitude, or both, and should be subdivided by these two variables.

Physiographic Regions

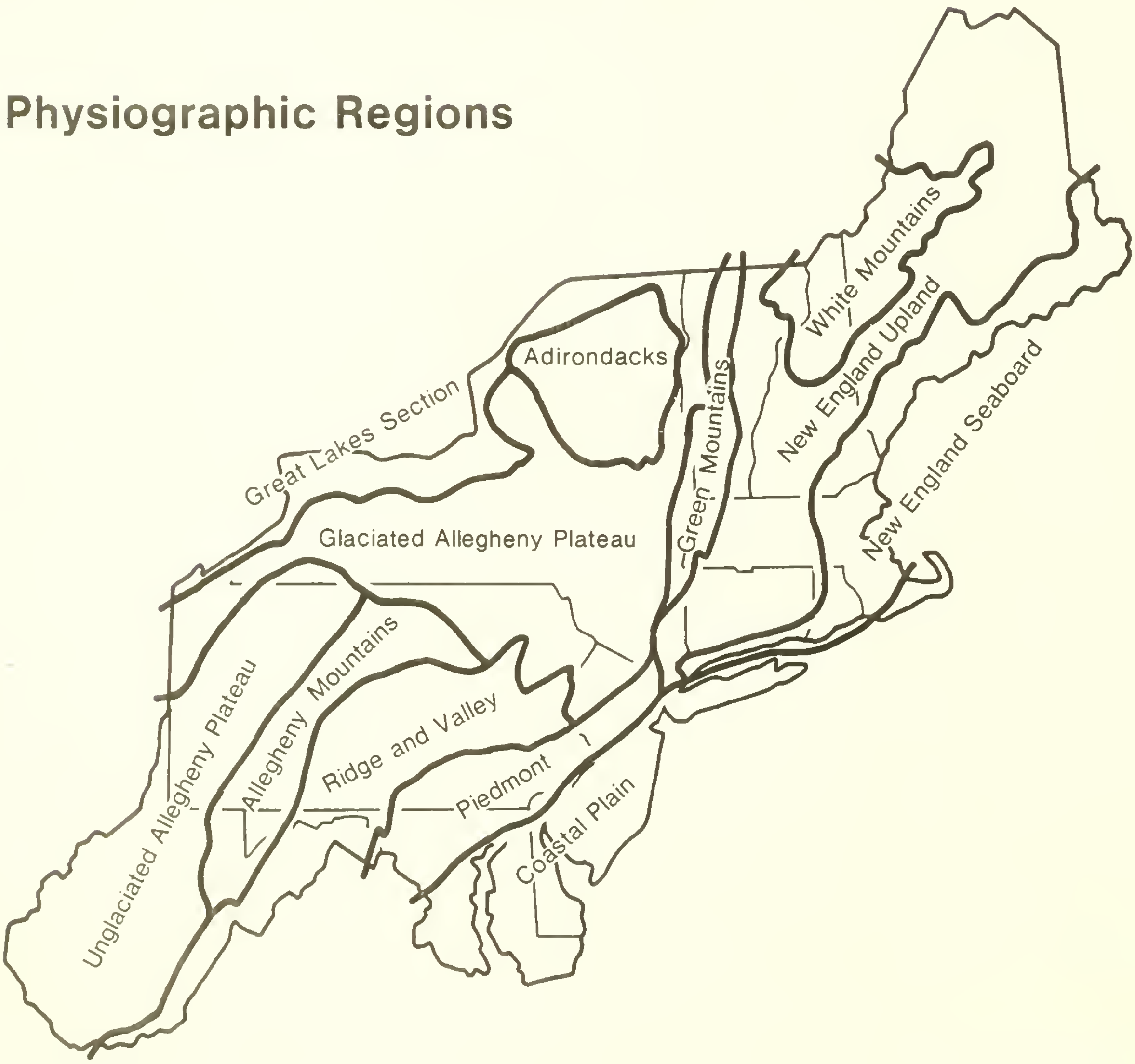

Figure 1.—Physiographic regions in the Northeast (Lull 1968).

Elevation

In the mountainous physiographic regions such as the White Mountains, Green Mountains, and Adirondacks there is a well-recognized change from hardwood to spruce-fir types above an elevation of 2,500 to 2,700 feet (Siccama 1974, Leak and Graber 1974). If we superimpose this elevational effect on the Green Mountain, Adirondack, and the southern part of the White Mountain physiographic regions, it will account for spruce-fir on Lull's map of the major forest regions (Fig. 2).

The influence of elevation is tempered to some extent by aspect: spruce-fir types tend to grow at lower elevations on colder aspects and higher elevations on warmer aspects. However, this pattern is often upset by habitat condition. For example, the spruce-fir cap on the south side of Mt. Chocorua in New Hampshire begins at 1,800 feet; this is because of habitat condition (shallow bedrock) rather than climatic effect.

Aspect has some additional effects on species mixes. On dry habitats such as shallow bedrock or outwash, oak tends to grow on southerly or westerly aspects in northern New England. And hemlock tends to predominate over red spruce as the aspect gets warmer (Leak 1976). However, I do not regard aspect as a major factor in classifying forest land because its effects are easily overshadowed by the habitat conditions discussed later, and because it is responsible for fairly minor shifts in the abundance of certain species near the limits of their range.

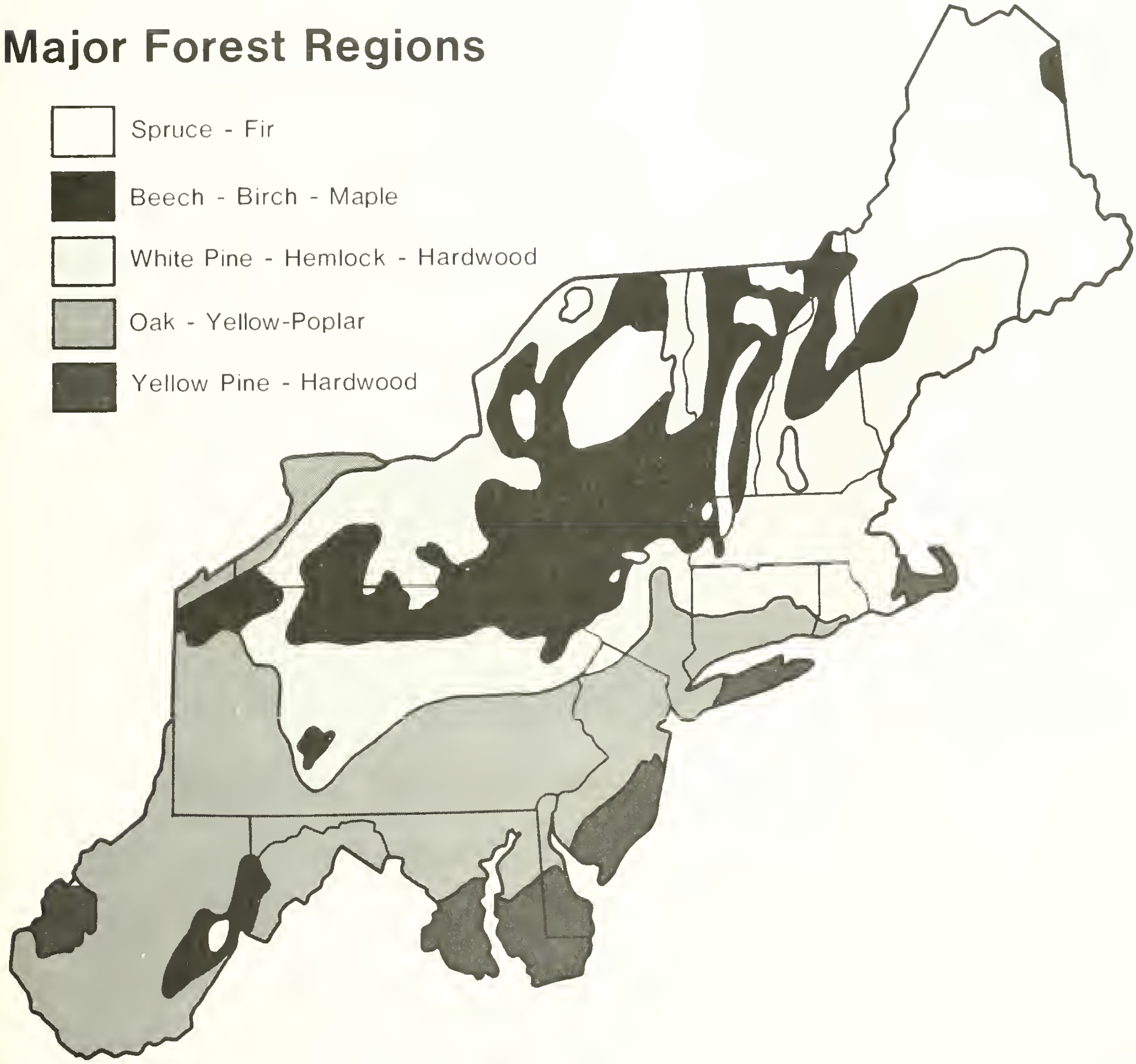

Figure 2.—Major forest regions in the Northeast (Lull 1968).

There is some evidence that as elevation decreases there are increases in productivity and volume (Bormann et al. 1970), the proportion of beech (Leak and Graber 1974), and the ratio of hemlock to red spruce (Leak 1976). However, in classifying forest land in New England, the major distinction is between stands above and below 2,500 feet.

Latitude

Some of the physiographic regions outlined by Lull (Fig. 1) span several (up to 7) degrees latitude. A comparison with Lull's map of forest regions (Fig. 2) indicates that some of the larger physiographic regions extend across two or three forest regions. For example, the New England seaboard is spruce-fir in the northern part and white pine (with hemlock and hardwoods) in the southern part. The White Mountain physiographic region is spruce-fir in the north and partly northern hardwoods in the south. Although these differences may be partly due to mineralogy and the prevailing types of glacial deposit, we also see evidence of a climatic effect related to latitude. Differences in latitude of about 1° seem important. This means that stands growing on a given mineralogy and soil material in a given physiographic region will be different in species composition and productivity if they differ in position by 1° latitude. For forest land classification purposes, we should divide physiographic regions into zones that extend no further than 1° latitude: for example, the northern and southern New England seacoast in Maine.

Mineralogy

We have known for some time that distinct differences in mineralogy affect species and productivity (Lutz 1958). Some scientists believe that in glaciated regions such as New England the influence of bedrock mineralogy is lost by thorough mixing of the glacial drift. However, Goldthwaite (1948) mapped the glacial drift in New Hampshire into three basic types derived from granite, slaty schist, and crystalline schist (Fig. 3). This was possible because most drift is moved by the glacier only a few miles from its source, though occasionally boulders move many miles. The distinctions among these mineralogies are reflected by differences in general soil texture, rock types, abundance of mica in the soil, and forest vegetation (Leak 1978b). Thus, mineralogy of the drift provides a further breakdown that should be recognized in any biophysical classification of forest land in New England.

Climatic-mineralogical Zones Summarized

In studying, classifying, or comparing forest vegetation in New England, account for the influence of climate and mineralogy. One likely approach is to begin with large physiographic regions (Fig. 1). The physiographic regions should be divided into subregions that extend no more than 1° latitude. Distinguish between areas above and below the critical elevational level, which is about 2,500 feet. Finally, distinguish broad mineralogical classes. These subdivisions result in zones that might include several hundred thousand contiguous or noncontinguous acres which is about the size of the zone that we discuss: granitic drift below an elevation of 2,500 feet in the southern half of the White Mountains. Much smaller units than these are required in planning and conducting forestry operations. The definition and mapping of these smaller units, called habitats, are discussed in the remainder of the paper.

Habitats

A habitat is a small unit of land, from a few acres up to a few hundred acres in size, with a given type of soil material (reflecting a given glacial process), landform and surface condition, and forest vegetation (climax-successional sequence). These are defined within given climatic-mineralogical zones because a certain soil material—for example, wet compact till—will support different vegetation in different climatic-mineralogical zones.

Habitats can be defined broadly or narrowly. For general planning purposes, habitats can be defined on the basis of soil substrate to a depth of 10 to 15 feet, general landform as interpreted from aerial photographs, and climax forest association. These broad units correspond to the ecological land types (ELT) being mapped on the White and Green Mountain National Forests.

In this paper, however, habitats are defined more narrowly on the basis of soil materials to a depth of 2 to 4 feet, landform plus surface conditions, and climax plus successional vegetation. I consider soil material to be the major variable: through its physical and chemical properties, soil material has a direct cause and effect on the nature and productivity of the vegetation. In classifying habitats, the soil materials at the base of the B horizon are examined to assess the original nature of the parent material; the objective is to determine what materials gave rise to the solum (surface and subsoil horizons). Materials within the solum are examined only to confirm the conclusions drawn from C-horizons materials. However, in two cases (enriched and poorly drained habitats), organic matter or excess water in the solum overrides the influence of C-horizon materials.

Early research leading to this habitat taxonomic classification was directed toward understanding the relation of soil materials to species composition and productivity of the vegetation (Leak 1976, 1978a). On the basis of this early research, which included 68 plots in old stands and 151 plots in successional stands on granitic drift, correlations between soil materials, species, and landform/surface conditions were developed. Currently, in mapping the taxonomic units, vegetation and landform/surface conditions are most useful because

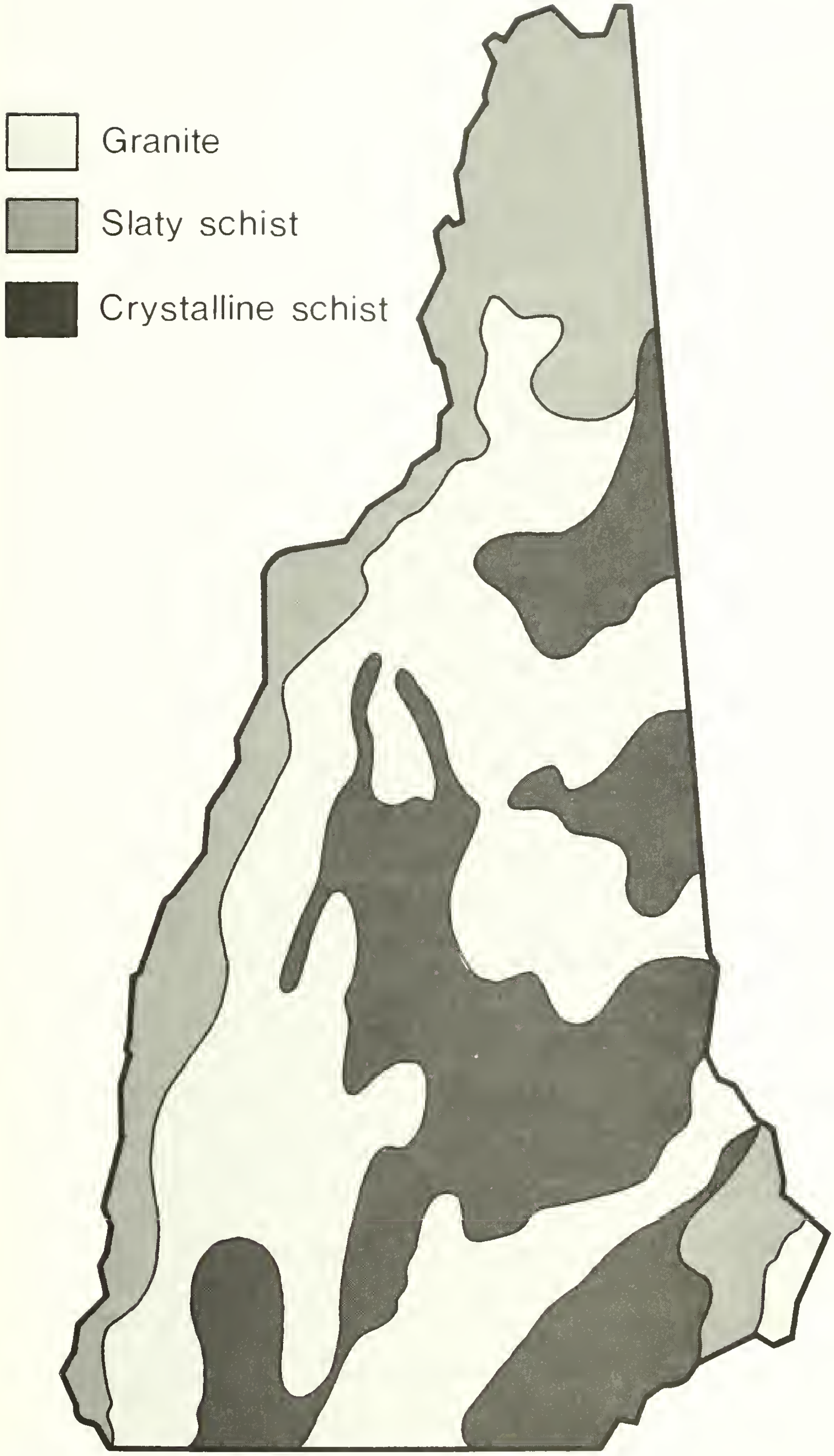

Figure 3.—Mineralogy of glacial drift in New Hampshire, adapted from Goldthwaite (1948).

they can be readily observed. Occasional checks on soil materials are made to confirm the designations. The goal is to obtain compatible and consistent relationships and common boundaries among all these variables.

A description is given for all habitats now recognized in the granitic drift below an elevation of 2,500 feet on the southern White Mountains. The descriptions are numbered according to the map designations used throughout this paper. The types of soil materials and landform/surface conditions will be found in most all glaciated regions, though it is possible that some additional classes would be required to meet local conditions. However, the associated vegetation will vary considerably depending upon climate and mineralogy. For example, the successional and climax vegetation found on granitic drift in the southern White Mountains of New Hampshire (Fig. 4) differs appreciably from the vegetation on schistose drift only a few miles away at the same latitude (Leak 1978b). The schistose drift supports noticeably more sugar maple and less beech in most habitats.

Habitat Descriptions (Taxonomy)

1. *Poorly drained*—This area is level with gray or heavily mottled mineral soil throughout the solum. Currently there are pools of standing water or free water in the upper solum. The climax is red spruce greater than hemlock. Successional stands are generally softwood greater than hardwood mixtures of red spruce, eastern hemlock, balsam fir, red maple, and birches (paper and yellow). Areas that have been cleared or repeatedly cut may be mostly red maple. Areas that are wet enough to preclude full occupancy to trees are better classed as wetlands.

   Successional stands result from clearcutting or heavy

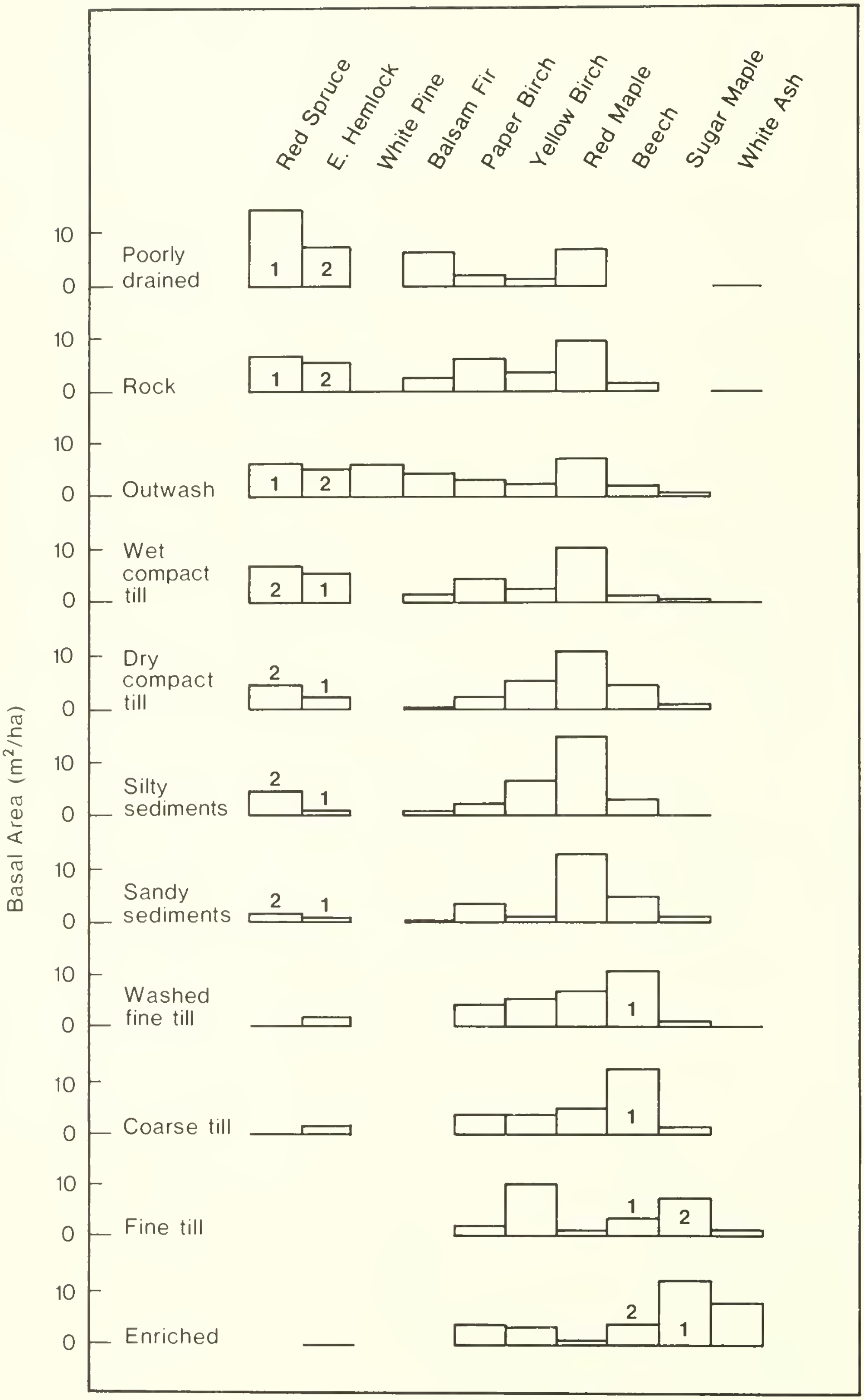

Figure 4.—Basal area in m^2/ha by species and habitat for successional stands on granitic drift in the southern White Mountains of New Hampshire. Number 1 refers to the most abundant and number 2 refers to the second most abundant species in older, climax stands.

partial cutting. Climax stands are defined as those stands composed primarily of tolerant species with the understory of similar species composition as the overstory.

2. *Shallow bedrock*—Bedrock, angular boulders, or nearly pure grus (weathered granite) is found as deep as 2 feet (65 cm) below the surface of the mineral soil. This area was plucked and scoured by the glacier, and may be on steep or moderate slopes. Ledges and rectangular boulders (not glacially worn) often are evident. Red spruce greater than hemlock is climax. Successional stands commonly have softwood greater than or equal to hardwood mixtures of red spruce, hemlock, red maple, and birches. On southern exposures, oak is often noticeably present; sometimes hophornbeam and white pine as well.

2A. *Shallow loose rock*—A matrix of partly rounded boulders is found up to 2 feet below the surface of the mineral soil. This condition apparently results from heavy rinsing action along streams or lakeshores. In some cases, the loose rock is sharp angled; apparently, this is colluvium for upslope. This habitat occurs on moderate to flat slopes often associated with drainage ways, or at the base of rocky slopes. The species are similar to those in 2, but productivity and the proportion of hardwoods are generally higher.

2B. *Exposed ledge*—In this area shallow bedrock and expanses of exposed ledge are very evident, resulting in scattered openings in the tree canopy. This area may have originated the same as shallow bedrock (2) and was followed by fire and erosion that exposed areas of ledge. The species are similar to those in 2, but stocking and productivity are lower.

3. *Outwash*—This habitat consists of sands or gravels that have been stratified, at least to some extent, and deposited by moving water. This definition includes both true outwash and ice-contact materials. Stones at the base of the B horizon are generally clean without silt caps. Outwash areas are flat to gently rolling or hummocky, free of surface rocks, and associated with streams or old drainage ways. The climax vegetation is red spruce greater than hemlock. Successional stands are softwood greater than or equal to hardwood mixtures of red spruce, hemlock, white pine, balsam fir, red maple and birches (especially paper birch). White pine is very characteristic of this habitat.

4. *Wet compact till*—Platy basal till compacted by the glacier is found at the base of the B horizon, and mottling or free water is very evident in the B horizon. This habitat is flat or concave and gently sloping with boulders pressed into the surface. The climax is eastern hemlock greater than red spruce. Successional stands are softwood greater than or equal to hardwood mixtures of hemlock, red spruce, red maple, and birches. Some ash is present but is moderate to low quality.

5. *Dry compact till*—This is basal till compacted by the glacier, but contains very little evidence of mottling or free water in the B horizon. C-horizon material usually is mottled and obviously supports water. This habitat is found on moderate upper slopes and knolls, usually above areas of wet compact till. The climax is hemlock greater than red spruce. Successional stands are hardwood greater than softwood mixtures of red maple, birches, beech, hemlock, and red spruce. Successional stands on this habitat contain noticeably more hardwoods than those on wet compact till (4).

5A. *Dry cemented till*—Hard crisp till is evident at the base of the B horizon. There is little or no evidence of free water or water-caused mottling. The habitat is found on low ridges or undulating topography but is not very common or widespread. The origin of this material is somewhat uncertain, but it seems to be cemented into a somewhat porous platy mass. The vegetation is similar to that in 5.

6. *Silty sediment*—This is very uniform (poorly graded) silt and fine sand deposited in slack water; up to 80 percent by weight is silt or finer particles. This material is somewhat sticky and massive and sometimes displays impeded drainage. Coarse fragments and stones are sometimes present, but lie within a matrix of sediments. The topography is level to gently sloping with mostly rock-free surfaces. The climax is eastern hemlock greater than red spruce. Successional stands are hardwood greater than softwood mixtures of red maple, birches, beech, hemlock, and red spruce; sometimes the softwoods are barely evident.

Figure 5.—A red maple/beech/paper birch/aspen stand growing on sandy sediments. Climax is hemlock/spruce, though few softwoods are evident in this successional stand. Biomass and cubic-foot production are adequate, but sawtimber production is low.

7. *Sandy sediment*—This sediment is similar to that in 6 in origin and occurrence. But the materials tend to be dry and single grained due to higher proportions of sand. However, there are too many fine particles for outwash. The climax apparently is eastern hemlock greater than red spruce. Successional stands are hardwood greater than softwood mixtures of red maple, birches (especially paper birch), beech, hemlock, and spruce. Balsam fir or white pine may be present (Fig. 5).

8. *Fine washed till*—The washed tills (8 and 9) apparently are ablational tills that were heavily water worked during deposition so that they contain sections of partially sorted material. The fine washed tills contain sufficient fine particles to produce very prominent silt caps on the buried rocks. These are loose tills which resemble a transition between sandy sediments and till. The topography is sloping or undulating with some surface rocks. The climax apparently is beech. Successional stands are mostly beech, red maple, and birches.

9. *Coarse washed till*—This is the most common of the washed tills. Rinsing action removed most of the silt and finer particles so that the remaining material is loose,

Figure 6.—Typical northern hardwoods on fine till. A good area for sawtimber production of sugar maple, yellow birch, and beech.

coarse, and sandy. However, minimal silt caps are found on buried stones. The topography is sloping or hummocky with moderate numbers of surface rocks. The climax is beech. Successional stands support beech, birches, and red maple. Hemlock and spruce may be present but not predominant.

10. *Fine till*—This till was dumped in place with little evidence of waterworking. The topography is irregular and often steep with many surface rocks. The climax is typical northern hardwoods characterized by beech and sugar maple. Successional stands contain beech, sugar maple, and birches (Fig. 6).

10C. *Fine till over compact till*—This recently recognized habitat is typical fine till underlaid with compacted till. The compacted layer generally is below the base of the B line or is discontinuous. The vegetation is similar to that in 10, but may have a few more ash and slightly higher site capacity. This habitat was recognized because of possible logging limitations caused by this habitat in the spring.

10S. *Silty fine till*—Fine tills may exhibit a noticeable silty feeling. Further research might indicate that these silty tills often are associated with 10C. The vegetation is similar to that in 10, but possibly with a slightly higher productive capacity.

11. *Enriched*—This habitat is small coves and benches in association with tills and compact tills. Organic matter or organic-coated fine materials are incorporated into the mineral soil. Horizonization is poor; the white A_2 generally is absent. Drainage varies from well to somewhat poor. Apparently, these areas are enriched by leaf litter, fine materials, or nutrient-rich water continually moving in from upslope. The climax is sugar maple. Successional stands are characterized by white ash and sugar maple with miscellaneous associated species.

A few additional habitat conditions were observed, but our experience with them is limited. Clay sediments are sometimes found and may be quite common in other climatic-mineralogical zones. These are similar to silty sediments, but the materials are much more plastic.

A very compact layer may form in silty or even sandy sediments. This layer acts as a barrier to water. Until further information becomes available, interpret this condition as similar to a wet compact till.

Relationships of Species Composition to Habitats

Climax vegetation is closely related to the soil conditions represented by groups of habitats. We used discriminant analysis to analyze differences in species composition for 63 prism plots in old climax stands composed mostly of tolerant species. First, a function was developed to segregate several habitats with a softwood climax (shallow bedrock, shallow loose rock, outwash, dry and wet compact tills, poorly drained) from those with a hardwood climax (coarse washed till, fine till, enriched).

The following discriminant function was developed:

$$Z = .4089\, X_1 - 1.3957\, X_2$$

Where:

Z = Function value with midpoint − 9.3614

X_1 = Basal area (m^2/ha) in softwood

X_2 = Basal area (m^2/ha) in tolerant hardwoods (beech and sugar maple)

By inserting values of X_1 and X_2, a value of Z is predicted. Values greater than − 9.3614 denote rock, outwash, compact till, or poor drainage. Values less than − 9.3614 denote tills or enriched sites.

The function was highly significant with a calculated F of about 240. The probability of misclassification was estimated at about .005, equivalent to 2.75 standard deviations. All 63 plots in the data set are correctly classified using this function.

A second discriminant function was developed for the 7 plots in coarse washed or fine till versus the 24 plots on enriched sites:

$$Z = -.8177\, X_1 + .8448\, X_2$$

Where:

Z = Function value with midpoint .2501

X_1 = Basal area (m^2/ha) in sugar maple

X_2 = Basal area (m^2/ha) in beech

The function was again highly significant with an F of about 15. Values of Z less than .2501 denote enriched sites. The probability of misclassification was estimated at about 10 percent. Four (all were enriched plots) of the 31 plots were misclassified using this function, an actual misclassification rate of 13 percent.

Because of the practical value of being able to recognize habitats on the basis of species composition alone, I developed a list of seven species groups that characterize the major stand conditions in New Hampshire and probably in adjacent states as well (Table 1). Recognition of these groups, coupled with a general assessment of soil moisture, provides some indication of likely habitats, climax species composition, best species, and possible management limitations. For silvicultural purposes, foresters may find it more convenient to assess stand potentials based on species composition alone—without examining soil materials or landform.

Mapping

Procedures

A strong taxonomic framework is a prerequisite to mapping. Although earlier plotwork showed that soil materials was the primary criterion for habitat definition, landform and tree species composition are the most useful criteria in the mapping phase.

Habitat mapping is best done with aerial photos on a scale of 1/15,000 to 1/20,000. Larger scales, though useful for a detailed examination of previously delineated areas, tend to obscure differences in landforms. Smaller scales mask certain small landform distinctions useful in detecting habitats; however, scales of about 1/40,000 are best for defining larger planning units at the ecologic land type level. The photos need to show sharp distinctions between softwoods and hardwoods; thus, leaf-free or infrared photography seems best.

Table 1.—Characteristics of seven forest types that represent major stand conditions in New Hampshire.

Forest[a] type	Soil[b] moisture	Likely habitats	Climax	Best species	Other productive species	Check for these management limitations
Sugar maple/ ash	Adequate	Enriched	Sugar maple	Sugar maple ash	Most hardwoods	Possible excess water in spring
	Wet	Enriched	Sugar maple	Sugar maple, ash	Most hardwoods	Excess water and possible occurrence of excess competition following clearcutting.
Beech/birch/ sugar maple	Adequate	Fine, or washed fine till, dry compact till	Beech sugar maple	Sugar maple, yellow, and paper birches	Any hardwood except ash	Possibly steep slopes and rocks
Beech/birch/ red maple	Dry	Coarse washed till, sandy sediments	Beech or softwoods	Paper birch (or possibly oak)	Red maple, beech, aspen	None
	Adequate	Washed fine till, dry compact till, silty sediments	Beech or softwoods	Paper birch, possibly yellow birch	Red maple beech, aspen	Possibly excess water in spring
	Wet	Wet compact till	Probably softwoods	Yellow birch paper birch softwoods	Red maple	Excess water and excess competition following clearcutting.
Hardwood/ hemlock/ spruce	Dry	Sandy sediments, outwash shallow to rock	Softwoods	White pine, other softwoods, paper birch, possibly oak	Red maple, aspen	Possible shallow bedrock
	Adequate	Silty sediments, dry compact till	Softwoods	Softwoods, birches	Red maple, aspen	Possibly excess water in spring
	Wet	Wet compact till, poorly drained	Softwoods	Softwoods, birches	Red maple	Excess water, windthrow, and excess competition following clearcutting
Hardwood/ white pine	Dry	Outwash, sandy sediments, shallow to rock	Softwoods	White pine, other softwoods, paper birch, perhaps oak	Red maple, aspen, beech	Possibly shallow bedrock
	Adequate-wet	Any	Uncertain Present stand probably old-field	White pine in present stand	Uncertain	Possibly excess water
Aspen/ paper birch	Dry	Outwash, sandy sediments	Softwoods	Paper birch, white pine, other softwoods, oak	Red maple, aspen	None
	Adequate-wet	Any	Uncertain. Present stand may be of fire origin	Paper birch in present stand	Uncertain	Possibly excess water
Oak/white pine	Dry	Washed coarse till, outwash, sandy sediments, shallow bedrock	Oak or softwoods	Oak, white pine, tolerant softwoods	Red maple, aspen	Possibly shallow bedrock

[a] Forest types: In general, the stand should contain at least 50 percent by basal area of the listed species. However, some judgment is needed in applying this rule. For example, a stand of hardwoods with an appreciable component of softwoods in the seedling understory should be considered hardwood-softwood or hardwood-white pine—because these softwoods could be featured in regenerating the stand.

[b] Soil Moisture: *Dry*—This condition occurs on areas of coarse sandy or gravelly outwash, sediments (sandy), and coarse washed till, as well as areas shallow to bedrock or boulders. The soils are loose, coarse, and always dry. Ground flora characteristics of dry areas are sometimes present: blueberries, wintergreen, bracken fern, several clubmosses, wild lily-of-the-valley. *Wet*—This condition occurs on poorly drained areas and wet compact tills. Evidence of excess water is evident at, or just under, the surface. *Adequate*—This condition occurs where soil texture is reasonably fine, a sandy loam or better. A well- to moderately-well drained pan may also occur.

A sample map of the Bartlett Experimental Forest (2,600 acres) is shown in Figure 7. Most of the habitats described earlier are found on this map. However, notice that some map units are combinations of associated habitats that cannot be separately mapped. In such cases, the habitat listed first is the predominant one. Since this map was completed, it has been suggested that classification and subsequent mapping of areas by broad percent-slope classes would assist in making interpretations.

Predelineation is the first step in habitat mapping. This consists of drawing lines around and tentatively naming logical map units based on steroscopic examination of photographs. Mapping is done directly on the photos, or overlays, with easily erasable marking pencil. Before predelineation work it is necessary to know or to determine through reconnaissance the types of materials in the area, their mode of occurrence, and their relationships with the tree vegetation. Elevational conditions on the Bartlett Forest are shown in Figure 8. The following guidelines were followed in predelineating habitats on the Barlett Forest.

Poorly drained (1)—This habitat is a flat area in low topographic positions. Stocking may be sparse or clumped. Softwoods are abundant in both young and old stands.

Shallow bedrock (2) and ledge (2B)—These habitats are in the uppermost elevational positions, or

Figure 7.—Habitat map of the Bartlett Experimental Forest, New Hampshire.

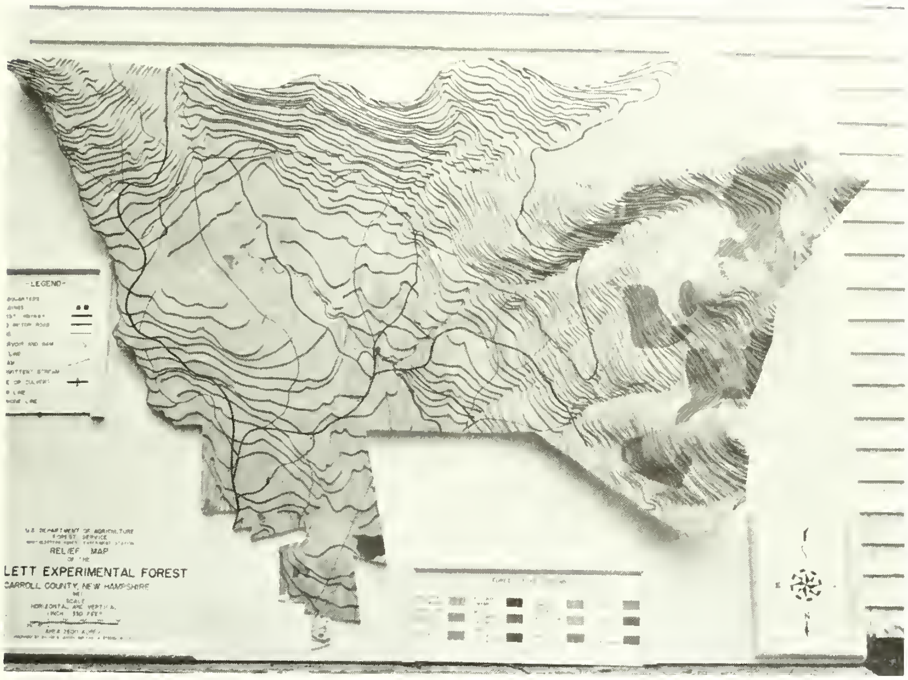

Figure 8.—Topographic model of the Bartlett Experimental Forest.

they may extend down from the upper elevations as fingerlike units. The ledge is visible in places. Spruce, fir, and/or hemlock are abundant in both young and old stands.

Shallow loose rock (2A)—This habitat usually is found along existing stream banks or old drainageways. Old stands are softwood and young stands are mixed wood.

Outwash (3)—An outwash area is a high, hummocky bank along existing streams (ice-contact materials) or mounded topography in the major valleys. Softwoods including some white pine are abundant in both young and old stands.

Wet compact till (4)—This material is on uniform, gently sloping areas at lower topographic positions. Softwoods are abundant in old stands, and mixed woods predominates in young stands. Drainage lines due to overland flow are sometimes evident. Streams are shallowly entrenched.

Dry compact till (5)—This compact till usually is found adjacent to and slightly above wet compact till. Topography can be gently sloping to convex and uniform. Old stands are softwood, but young stands are mixed wood or mostly hardwood.

Dry cemented till (5A)—This habitat was not mapped on the Bartlett Forest. It is commonly an area of softwood (old stands) or mixed wood (younger stands) on low ridges. This habitat is difficult to distinquish on photographs.

Silty (6) and sandy (7) sediments—These habitats are found on gently sloping or rolling, well drained topography at lower elevations. Old stands are softwood and young stands are mixed wood or hardwood. Streams are steep banked and deeply entrenched.

Washed tills (8, 9)—Washed tills are characterized by hardwood stands with some softwood admixture on sloping or rolling topography at mid to lower elevations. On the Bartlett Forest, most of the washed tills are found just above and below the major slope break between the upper and lower elevations of the forest (Fig. 8). Streams are uncommon within these units, though well entrenched streams may border them.

Fine till (10, 10C, 10S)—This habitat has hardwood stands on moderately steep and irregular topography at mid to upper elevations.

Enriched (11)—Enriched habitats commonly are too small to be detected on photographs. On the Bartlett Forest, this habitat usually occurs at the slope break between the upper and lower elevations. In other areas, the alluvial soils with hardwoods adjacent to major streams commonly are typed as enriched.

After predelineation, each mapped unit or a sample of the units is examined in the field to confirm the boundaries and the habitat designations. Boundaries generally are quite accurate; however, habitat names frequently are revised in the field. In each mapped unit examined, a pit is dug to determine the nature of the soil materials; additional auger borings are taken to check for uniformity of materials throughout the unit. It is during field checking that one or two associated habitats often are recognized and designated along with the primary habitat designation.

Based on a random 1,050-point sample of the finished map, the primary habitat conditions on the Bartlett Forest are shallow bedrock, wet compact till, coarse washed till, and fine till. These each account for about 18 percent of the forested area (Table 2). Poorly drained and enriched habitats each account for less than 1 percent of the area. The remaining habitats each account for 2 to 5 percent of the area.

Relation of Habitat Map Units to Other Map Units

Two other land classification schemes are used in the area of the Bartlett Forest: the ecologic land types mapped by the White Mountain National Forest and the standard soil survey using soil series or associations mapped by the Soil Conservation Service (SCS). Recent maps of both systems were available for the Bartlett area. The soils

Table 2.—Percentage of the Bartlett Experimental Forest in each habitat based on 1,050 points.

Habitat	Percentage of area
Poorly drained(1)	0.4
Shallow to bedrock (2 and 2B)	18.2
Loose rock(2A)	5.2
Outwash(3)	2.4
Wet compact till(4)	17.5
Dry compact till(5)	5.6
Silty sediments(6)	3.6
Sandy sediments(7)	5.0
Fine washed till(8)	5.0
Coarse washed till (9)	18.6
Fine till (10, 10C, 10S)	17.6
Enriched(11)	.9
Total	100.0

Table 3.—Numbers of points falling within each habitat/soil series combination[a]

Habitats	Well-drained till (BVC, BVE, BVF, HOE)	Well-drained pan (BEE, MEE, MEF)	Well-drained to moderately well-drained pan (MFC)	Moderately well-drained pan (PLC)	Shallow to bedrock (LVF, LYF, RPF, CDE)
Poorly drained(1)	—	—	2	2	—
Shallow to bedrock(2)	12	36	9	—	134
Loose rock(2A)	—	8	40	6	1
Outwash(3)	—	23	2	—	—
Wet compact till(4)	4	9	130	40	—
Dry compact till(5)	7	27	25	—	—
Silty sediments(6)	—	—	34	4	—
Sandy sediments(7)	1	—	43	9	—
Fine washed till(8)	11	10	30	2	—
Coarse washed till(9)	1	99	95	—	—
Fine till(10, 10C, 10S)	83	55	46	—	1
Enriched(11)	1	—	8	—	—

[a] Soil association definitions:
BEE—Becket very stony fine sandy loam association, steep
BVC—Berkshire very stony fine sandy loam association, sloping
BVE—Berkshire very stony fine sandy loam association, steep
BVF—Berkshire very stony fine sandy loam association, very steep
CDE—Canaan-Redstone very rocky gravelly fine sandy loam association, steep
HOE—Hermon very stony fine sandy loam association, steep
LVE—Lyman-Berkshire very rocky fine sandy loam association, steep
LYF—Lyman-Rock outcrop association, very steep
MEE—Marlow very stony fine sandy loam association, steep
MEF—Marlow very stony fine sandy loam association, very steep
MFC—Marlow-Peru very stony fine sandy loam association, sloping
PLC—Peru very stony fine sandy loam association, sloping
RPF—Rock outcrop-Lyman association, very steep

of the area were described by Diers and Vieira (1977) and by Pilgrim and Harter (1977). By drawing a map sample of 1,050 points, we were able to compare habitats, ecologic land types, and soil associations. Examination of areas in the field provided at least a partial explanation for some of the discrepancies among mapping approaches.

Habitats versus soil associations—Habitats (Fig. 7) and soil associations (Fig. 9) followed similar boundaries: similar units of land were designated under both approaches. The similarity between mapped unit designations is shown in Table 3. The soil associations were grouped into general classes of parent materials.

The few points that fell in the poorly drained habitat were cross-classified as well-drained to moderately well-drained soils with a pan. This is a reasonable association because poorly drained areas are generally surrounded by moderately drained to somewhat poorly drained pan soils.

The shallow-to-bedrock habitat is similar to the soil associations reflecting shallowness to bedrock; 70 percent of the points are similar.

The habitats classed primarily as loose rock were predominately cross-classified as well-drained to moderately well-drained soils with a pan. This association was not surprising because most of the loose rock was mapped along waterways at lower elevations, and loose rock supports vegetation somewhat similar to that of pans. However, because loose rock is a reasonably common habitat, which often occurs in association with other habitats and has different hydrologic

Figure 9.—Soil survey map of the Bartlett Experimental Forest.

properties than pan, the importance of loose rock in determining forest composition and utilization should be evaluated further.

The small amount of outwash habitat in the forest was mostly cross-classified as well-drained soils with a pan. This habitat was not in the usual position for outwash; it was along a stream at fairly high elevations and easily could be mistaken. In general, outwash is classified in similar fashion under all three systems examined in this study.

Most wet compact till (71 percent) was cross-classified as well-drained to moderately well-drained soils with a pan. The dry compact till fell mostly (88 percent) into the well-drained and well-drained to moderately well-drained categories of pan. Thus, there is a reasonable association between the habitat and soil association approaches in mapping these categories.

Both the silty and sandy sediments were primarily cross-classified as well-drained to moderately well-drained soils with a pan. In the Bartlett Forest, both of these habitats were in lower slope positions where pan commonly is found. However, the sediments appear to offer different opportunities than pan with regard to operability, productivity, and potential for intensive management.

Most of the coarse washed till and, to a lesser degree, the fine washed till were cross-classified as well-drained to moderately well-drained soils with a pan. About one-fifth of the fine washed till fell into the soils category of well-drained till, which seems like a more logical category. One reason why there is some discrepancy in the mapping of these habitats is that the washed tills seem to occur in complex associations. Much of the washed till I mapped seemed to be underlaid with pan, which surfaced occasionally. On the basis of plot work, I feel that the washed tills have considerably different management potential than the pans or the typical well-drained tills (Berkshire for example). For example, the coarse washed tills appear to produce heavy amounts of beech; the pans lean toward softwoods, and the typical (unwashed) tills produce rich northern hardwoods (sugar maple/beech).

Approximately 45 percent of the fine till habitat was cross-classified as well-drained till soils (a logical category), and most of the remainder fell into well-drained to moderately well-drained soils with a pan. Field examination of several areas with the SCS state soil scientist, S. Pilgrim, indicated that some areas classed as fine till were underlaid with a firm, platy till and classified as well-drained soils with a pan by SCS mapping. I did not class these as pans because the firm layer seemed to be below the rooting depth, and did not seem to be mottled or discolored, and because the area supported typical northern hardwoods. Since then, a new habitat category (10C) was developed to represent fine till over compact till. This was done because of the possible effects of this pan on operability and site potential (a positive effect perhaps). However, this sort of well-drained pan needs to be mapped separately from the areas mapped as dry compact till.

The few points that fell in enriched habitats were cross-classified as well-drained to moderately well-drained soils with a pan. Enriched habitats are limited in size and number, and apparently there is no analogous soil series. However, enrichment often is mapped in association with other habitats. Thus, this condition may be more important than its acreage indicates.

Habitats versus ecologic land types—Table 4 gives the association between habitats and ecologic land types (ELT). Many changes have been made in ecologic land typing since these data were developed, so only a brief and general comparison will be made.

The poorly drained and shallow-to-bedrock habitats were similar to the ELT classifications of imperfectly drained ablational tills and shallow-to-bedrock sites.

Habitats characterized by loose rock and outwash were too small and scattered to be reflected in the ecologic land types.

The wet compact till habitat was similar to the ELT classifications of basal till or imperfectly drained basal till. However, a large number of points (38 percent) fell under well-drained tills. Pans and imperfect drainage sometimes are difficult to assess on aerial photographs without intensive ground checking. The dry compact till habitats also were split between the land types of basal till and well-drained till.

Silty and sandy sediments were classed both as imperfectly drained ablational tills and well-drained tills. This is understandable because some sediments seem well-drained, and others show some evidence of imperfect drainage. The concept of sedimentation is now built into the ELT system.

Fine washed tills were similar to the ecologic land type representing well-drained tills—a logical association.

Much of the coarse washed till habitat was cross-classified as basal till or imperfectly drained ablational till. As mentioned earlier, the coarse washed tills often are complex areas, sometimes underlaid with pan. The ELT system, which classifies substrata to a depth of about 10 feet, could understandably list these as basal till or imperfectly drained areas. However, I think that areas with shallow versus deep pan can be quite different in species, productivity, and operability.

Habitats classed as fine till commonly were cross-classified as basal till. This difference again reflects the ELT approach of looking

Table 4.—Numbers of points falling within each habitat/ecologic land type combination[a]

Habitat	Well-drained tills(5)	Well-drained bouldery tills(5C)	Well-drained to moderately well-drained basal till(3)	Imperfectly drained ablational till(6B)	Shallow to bedrock(2)
Poorly drained(1)	—	—	1	3	—
Shallow to bedrock(2)	—	59	7	1	124
Loose rock(2A)	1	—	9	44	—
Outwash(3)	—	—	24	1	—
Wet compact till(4)	70	2	38	73	—
Dry compact till(5)	30	—	28	1	—
Silty sediments(6)	11	—	—	27	—
Sandy sediments(7)	27	—	1	25	—
Fine washed till(8)	41	—	—	12	—
Coarse washed till(9)	5	1	134	55	—
Fine till(10, 10C, 10S)	6	58	116	4	1
Enriched(11)	6	—	3	1	—

[a] Ecologic Land Types:

ELT 2—Softwood knolls, ridges, and steep side slopes with ledgy, bouldery shallow sites—these typically are shallow to bedrock with a spruce-fir climax at higher elevations, and with more hemlock and oak at lower elevations.

ELT 3—Hardwood with softwood mountain side slopes with moderately deep soils to hardpan—these are well-drained to moderately well-drained soils underlaid by impermeable basal till.

ELT 5—Hardwood lower mountain slopes and broad valley floors with very deep ablational tills—these are well-drained tills supporting northern hardwood stands.

ELT 5C—Hardwood smooth steep upper mountain slopes with deep, very bouldery ablational tills—these are bouldery, well-drained tills, high in coarse fragments, supporting more beech than ELT 5.

ELT 6B—Hardwood flats and swales with imperfectly drained organic surfaces over wet ablational tills—these are less than well-drained soils, apparently due to the influence of pan and lower slope position, supporting a hardwood-softwood mixture.

at deeper layers than the habitat system.

The few enriched areas were too small to be considered under the ELT system.

Summary on mapping correlations—Keep in mind the uncertainties involved in comparing mapping approaches. Apparent discrepancies can arise because of differences in: taxonomic or mapping criteria, precise definitions of these criteria, the weighting of criteria in multifactor systems, and the purity of the mapping systems (the variability allowed within units). Although all of these sources of uncertainty have not been evaluated in detail, it seems evident that two technical subjects require additional discussion and specification.

1. We need to look more closely at the types of pans that influence productivity and operability. The problem seems especially important with pans that are well-drained to moderately well-drained. Some pans support rich northern hardwoods; others that are well-drained to moderately well-drained support mediocre hardwoods and have a softwood climax.

2. The concept of washed or waterworked till needs additional evaluation. We should reexamine our definitions of sediments—what they are and how they influence vegetation. The problem is that areas mapped as well-drained tills by the SCS might be classified as sediments or washed tills under the ELT or habitat approaches. Because of different definitions, the coordination of information from the three approaches is difficult.

Interpretations

To develop information on species relationships and productivity of the habitats mapped on the Bartlett Forest, 145 10-factor prism plots were measured. These plots were systematically located to sample the range of conditions in 27 stands representing 12 habitat mapping units. The sample included even-aged successional stands (mostly about 100 years old) composed of both tolerant and less-tolerant species as well as a few uneven-aged climax stands composed primarily of tolerant species. The stands were uncut during the last 50 years or more.

On each plot, trees were tallied by species and dbh class (over 1.0 inch). Height and age were determined on one potential site index tree per plot, if available. The presence of trees less than 1.0 inch dbh, shrubs, and herbs was recorded by species on eight 1-m^2 plots per prism point.

Species Composition

Species composition in basal area per acre (trees over 1.0 inch dbh) was determined for both successional stands (Fig. 10) and climax stands (Fig. 11). These results closely follow earlier guidelines on the relations of species composition and succession (Fig. 4) to habitat in granitic drift (Leak 1978a). Softwoods are evident in successional stands on poorly drained, bedrock, wet compact till, and silty sediments habitats; red maple is the predominant hardwood on these habitats. The proportion of softwoods in these successional stands varies considerably, however, depending upon cutting history. If an understory was left in the early cuttings around 1900, softwoods are abundant. If the cutting was complete, hardwoods predominate.

Dry compact till and sandy sediments support red maple/beech/birch stands. The washed tills are primarily hardwood stands with beech predominating; some hemlock is evident as well. The enriched habitats are characterized by sugar maple and white ash. Results from the climax stands indicate that beech and sugar maple characterize the fine tills; these species together with birches also typify successional stands. Hemlock and red spruce are climax on the other habitats represented in Fig. 11.

Climax species composition is not necessarily static, however. General observations[1] indicated that beech and sugar maple on fine till habitats tend to alternate in abundance. Results from two climax stands on fine till illustrate this phenomenon:

[1] Personal communication, Stanley M. Filip, retired research forester.

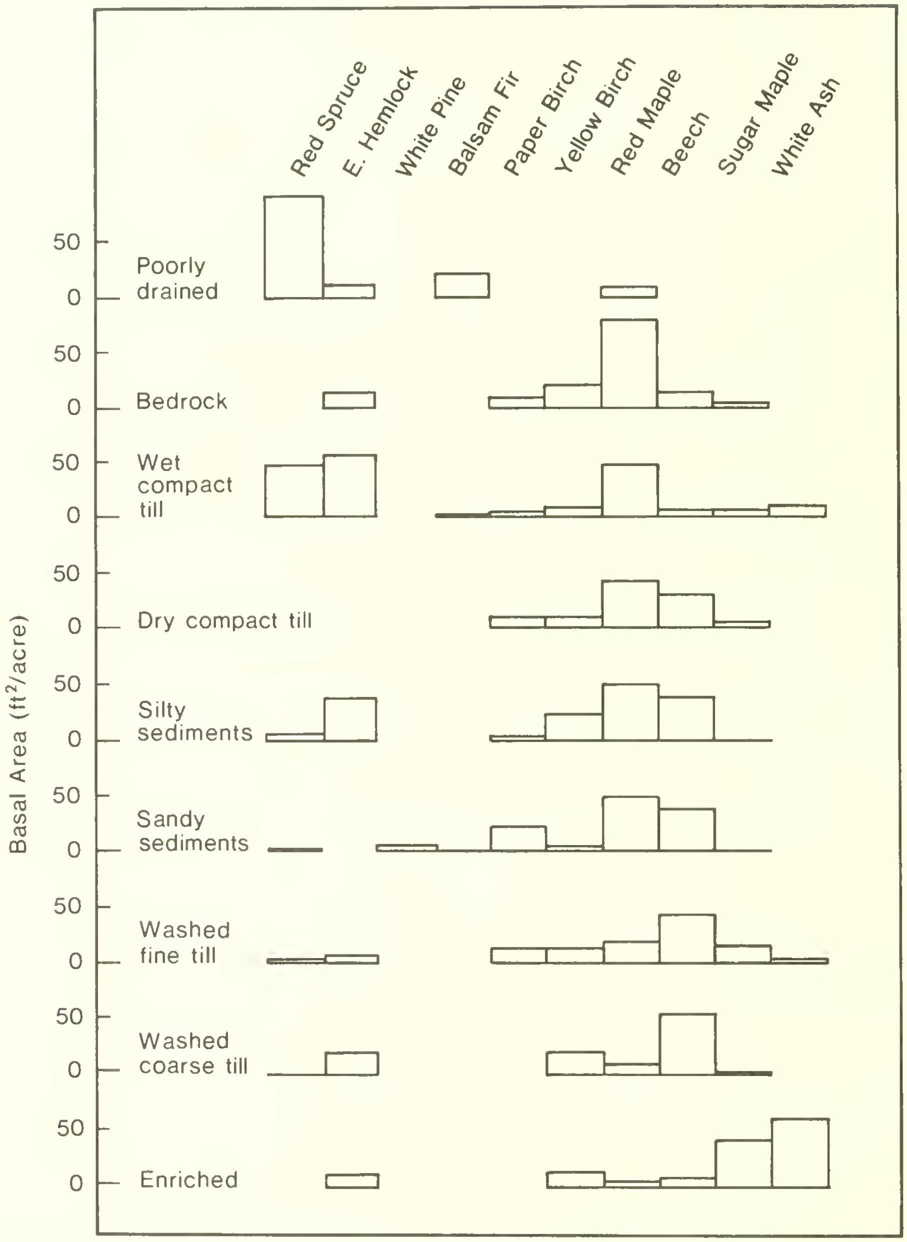

Figure 10.—Basal area per acre by habitat and species for successional stands on the Bartlett Experimental Forest.

	Beech		Sugar maple	
	2-8 inches dbh	*10 inches dbh +*	*2-8 inches dbh*	*10 inches dbh +*
	(basal area in ft²)			
Compartment 22	6.7	86.7	16.7	6.7
Compartment 35	11.7	26.7	1.7	45.0

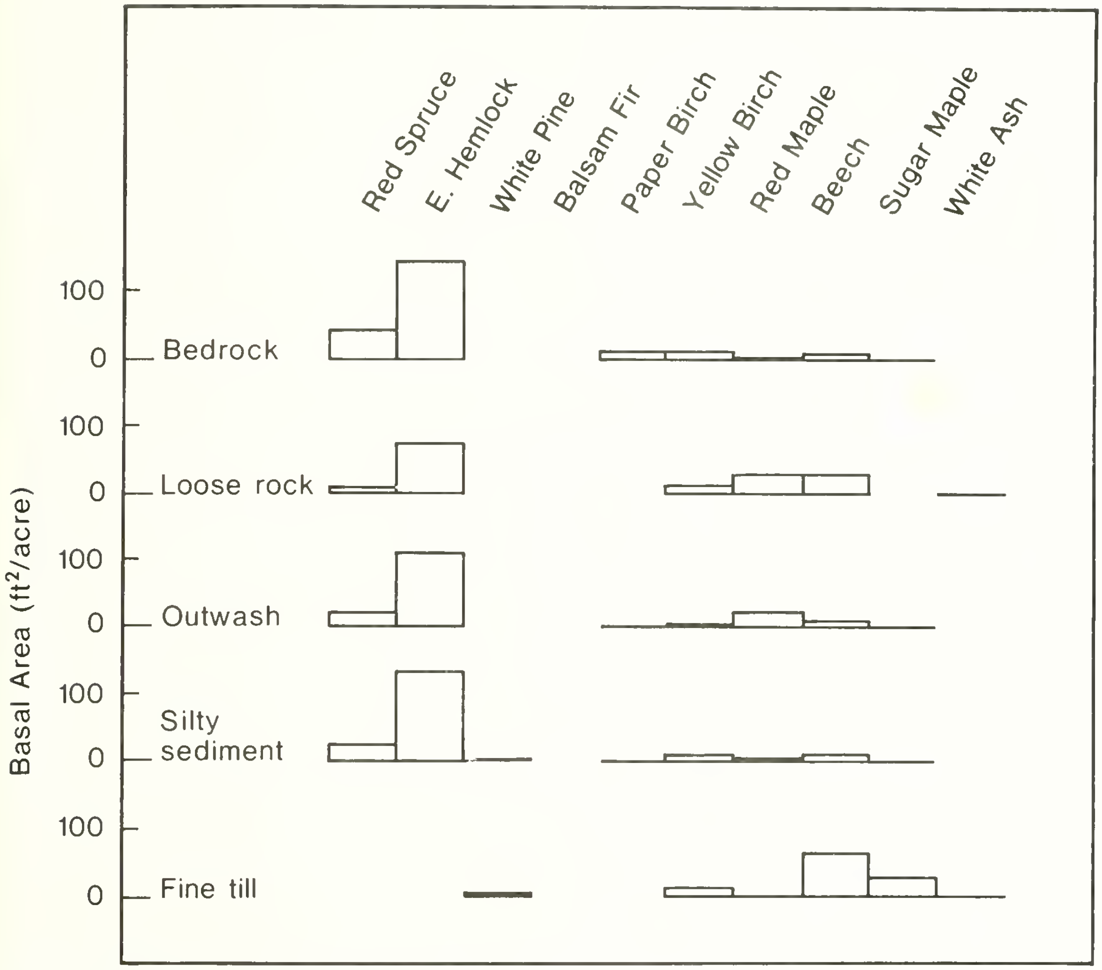

Figure 11.—Basal area per acre by habitat and species for climax stands on the Bartlett Experimental Forest.

On Compartment 22, beech is abundant in the overstory and sugar maple predominates in the understory. On Compartment 35, the situation is reversed. Apparently, species alternation is characteristic of northern hardwoods on fine till, but additional long-term observation will be needed to confirm this hypothesis.

Although species of shrubs and herbs have proved to be of diagnostic value for western habitats (Pfister and Arno 1980) and some earlier eastern classifications (Westveld 1951), these species have not yet been recognized as criteria for defining habitats in the White Mountains.

Results from the Bartlett Forest indicate that certain habitats support a much richer flora (greater numbers of species) than others. The greatest numbers of herbaceous species are found on enriched, sandy sediment, and wet and dry compact till habitats; in several instances, these same habitats

Table 5.—Average numbers of tree, shrub (including small tree), and herbaceous species per stand by habitat and successional stage.

Habitat	Successional stage	Number of m^2 plots	Average number of species		
			Trees	Shrubs and small trees	Herbs
Enriched(11)	Successional	80	4.0	4.0	11.0
Fine till(10, 10C, 10S)	Climax	96	4.5	3.0	4.5
Coarse washed till(9)	Successional	80	6.0	2.5	2.0
Fine washed till(8)	Successional	136	6.0	3.3	5.0
Sandy sediments(7)	Successional	128	7.3	4.7	15.7
Silty sediments(6)	Climax	40	7.0	3.0	.0
	Successional	96	3.5	3.5	7.0
Dry compact till(5)	Successional	80	8.5	4.5	12.0
Wet compact till(4)	Successional	192	6.8	6.5	14.2
Outwash(3)	Climax	56	3.0	3.0	1.0
Bedrock(2)	Climax	56	2.0	2.0	2.0
Loose rock(2A)	Climax	48	6.0	3.0	3.0
	Successional	56	4.0	4.0	8.0
Poorly drained(1)	Successional	16	5.0	4.0	2.0

support more tree or shrub species as well (Table 5). Richness bears no clear relationship to moisture, because the sandy sediments are well-drained to excessively well drained and the other three rich habitats tend to be moderately well-drained or wetter.

Species composition of the understory was somewhat variable, though certain patterns existed (Table 6). We examined only those species or species groups of the understory that were present with at least 5 percent frequency in all stands in a given habitat. The frequency of tree species (up to 1.0 inch dbh) resembled the species composition of the overstory: sugar maple and ash were common on the enriched habitats, sugar maple and beech predominated on fine till, and so on. However, some of the demanding species were found in the understory on habitats where they probably will not succeed; for example, although sugar maple occurs with 10 percent frequency on sandy sediments and white ash with 12 percent frequency on dry compact till, I could not expect either species to be common in the overstories on these habitats.

Shrubs and small trees were not particularly diagnostic. However, Canada yew was found mostly on areas underlaid with loose rock. Poorly drained habitats were characterized by sheeplaurel, blueberry, wintergreen, and wild raisin. With regard to herbaceous species, wild oats were most common on enriched habitats. Starflower was characteristic of sandy sediments. Clintonia and wood sorrel were abundant on wet compact till, and sphagnum and goldthread were unique on the poorly drained areas. Although there were appreciable differences among habitats, the overall herbaceous species composition resembled the oligotrophic (low base) series reported by Siccama and others (1970).

In general, knowledge of understory species composition seems to be useful in helping to identify *certain* habitats, but is not consistent enough to be used as a major criterion in habitat taxonomy or mapping.

Stand Productivity

Aboveground biomass per acre was determined by applying the equations by Whittaker and others (1974) for stems and branches to the prism-plot information from the Bartlett Forest. Biomass for species not represented by the Whittaker equations was estimated by using his sugar maple equations and correcting for specific gravity. To supplement this information, I included previously reported plot information (Leak 1979) for sapling and pole-timber stands from granitic areas near the Bartlett Forest. Curves of biomass per acre over age were nearly identical for most hardwood habitats (hardwood climax: habitats

Table 6.—Average frequency (percent occurrence on 1-m² plots) of tree, shrub (including small trees), and herb species per stand, by habitat and successional stage (includes only those species greater than or equal to 5 percent frequency on all areas in each habitat/successional category).

Species	Habitat and stand category													
	Enriched (11)	Fine till (10, 10C 10S)	Coarse washed till (9)	Fine washed till (8)	Sandy sediments (7)	Silty sediments (6)		Dry compact till(5)	Wet compact till(4)	Outwash (3)	Bedrock (2)	Loose rock (2A)		Poorly drained (1)
	Successional	Climax	Successional	Successional	Successional	Climax	Successional	Successional	Successional	Climax	Climax	Climax	Successional	Successional
						TREES								
Beech	32	52	68	69	57	25	44	45	17	—	—	58	9	—
Sugar maple	68	51	15	22	10	—	—	—	—	—	—	—	5	—
Red maple	—	—	15	37	31	22	—	—	14	—	—	—	—	56
Yellow birch	—	—	—	—	—	—	—	—	—	—	—	—	—	19
White ash	28	—	—	18	—	—	—	12	—	—	—	—	—	—
Red spruce	—	—	—	—	—	28	—	—	—	25	21	19	—	31
E. hemlock	—	—	—	—	—	40	14	—	—	21	14	33	—	56
Balsam fir	—	—	—	—	—	—	—	—	14	—	—	—	—	6
						SHRUBS								
Hobble bush	42	35	16	33	—	12	44	64	42	11	—	29	43	—
Striped maple	36	40	—	—	16	5	—	34	40	—	11	17	12	—
Canada yew	—	—	—	—	—	—	—	—	—	—	—	8	5	—
Blueberry	—	—	—	—	—	—	—	—	—	—	—	—	—	62
Wintergreen	—	—	—	—	—	—	—	—	—	—	—	—	—	38
Sheeplaurel	—	—	—	—	—	—	—	—	—	—	—	—	—	25
Wildraisin	—	—	—	—	—	—	—	—	—	—	—	—	—	6
						HERBS								
Wildoats	49	—	—	—	—	—	—	—	—	—	—	—	—	—
Indian cucumber	20	—	—	—	25	—	8	30	—	23	—	12	5	—
Wild lily-of-the-valley	—	—	—	—	85	—	—	26	—	—	—	—	—	—
Starflower	—	—	—	—	51	—	—	—	—	—	—	—	—	—
Sarsaparilla	—	—	—	—	18	—	—	24	—	—	—	6	20	—
Clubmoss	—	—	—	—	36	—	—	—	—	—	—	—	5	—
Trillium	—	—	—	—	—	—	—	6	—	—	—	—	—	—
Clintonia	—	—	—	—	—	—	—	—	22	—	—	—	—	—
Wood sorrel	—	—	—	—	—	—	—	—	36	—	—	—	—	—
Moccasin flower	—	—	—	—	—	—	—	—	—	—	—	—	5	—
Woodfern	—	—	—	—	—	—	—	—	—	—	—	—	7	—
Sphagnum	—	—	—	—	—	—	—	—	—	—	—	—	—	94
Goldthread	—	—	—	—	—	—	—	—	—	—	—	—	—	6

number 8 to 10) and softwood habitats (softwood climax now supporting hardwoods, mixed wood, or softwoods: habitats number 2 to 7) (Fig. 12). Climax hardwood stands[2] averaged about 40,000 dry pounds per acre heavier than softwood stands though there were too few observations to detect a significant difference. The white ash/sugar maple stands characteristic of enriched habitats averaged greatest in biomass; one softwood stand on a poorly drained habitat averaged least. The equations for hardwood and softwood standing aboveground dry biomass in thousands of pounds per acre are:

$$\text{Hardwood: Dry Wt.} = 1.2955 + 3.2182\,(\text{age}) - 15.4854\,(\text{age}^2/1000)$$
$$n = 11$$
$$R^2 = .97$$

$$\text{Softwood: Dry Wt.} = -0.8552 + 3.1728\,(\text{Age}) - 14.8337\,(\text{Age}^2/1000)$$
$$n = 28$$
$$R^2 = .94$$

These equations were fitted to points representing stands of varying size and age. Thus, the R^2 values provide a rough measure of goodness of fit.

Note that these curves of biomass over age are substantially different from the living biomass accumulation curve reported by Bormann and Likens (1979, Fig. 2, Chapter 6). The Bormann-Likens curve peaks sharply at about age 175; whereas, my curves generally flatten off at age 100 to 120. The Bormann-Likens curve is essentially a straight line from origin to peak; whereas, my curves represent the more natural parabolic growth form. The Bormann-Likens model shows a substantial drop from peak biomass accumulation to the climax or

[2] These climax stands contained trees of up to about 200 years old, so climax stand age in Figure 12 was set at 200 years.

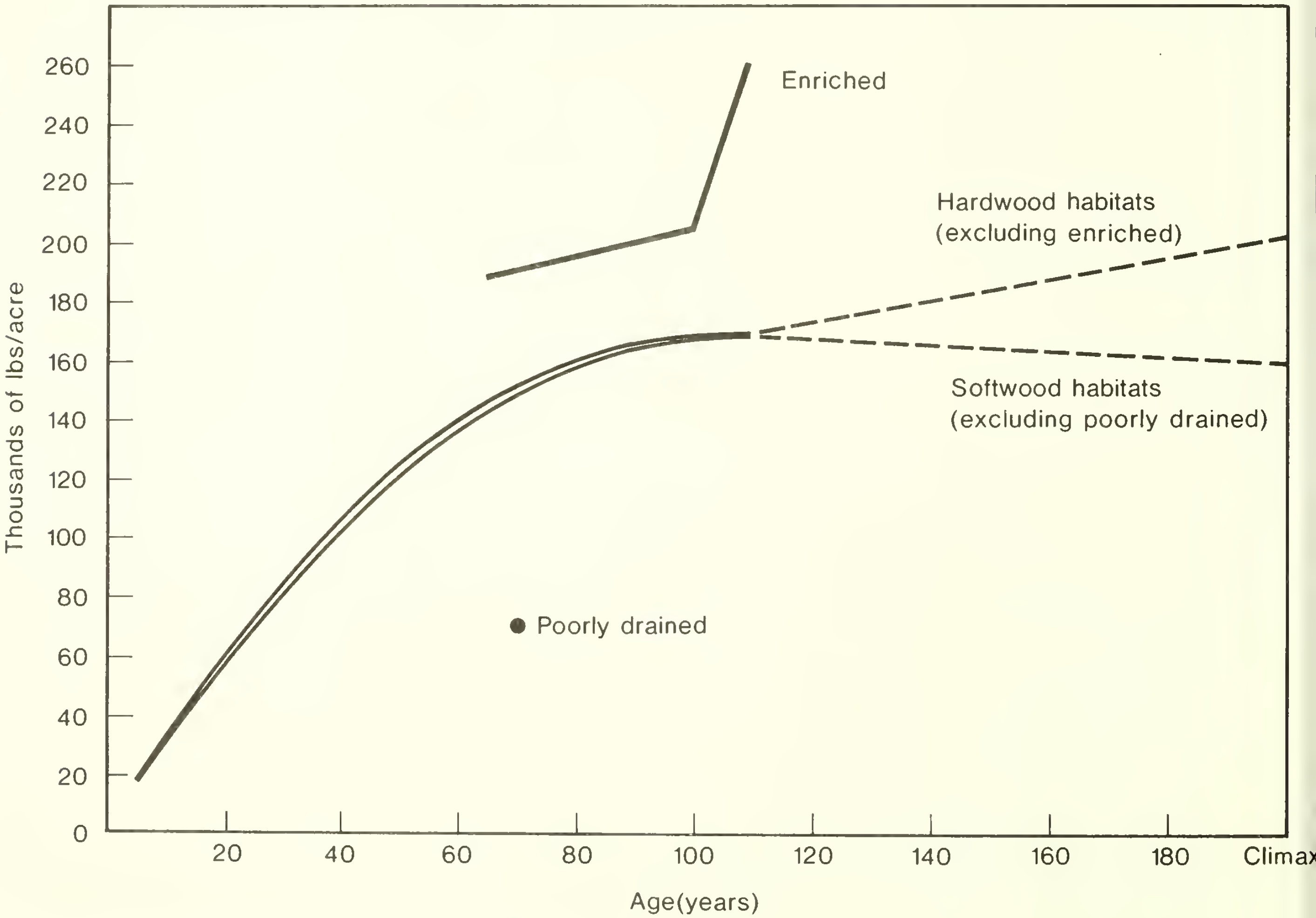

Figure 12.—Aboveground biomass (stems and branches) in dry weight over stand age by habitat groups.

steady state. My curves indicate a slight drop in biomass of climax softwood stands and a slight increase in biomass of hardwoods. The Bormann-Likens curve peaks at about 490 metric tons per hectare of living biomass, which equals 437,000 pounds per acre. If we reduce this by approximately 20 percent to account for roots, twigs, and leaves, the aboveground biomass in stems and branches is about 350,000 pounds per acre. On the Bartlett Forest, the estimated maximum aboveground biomass per acre for climax northern hardwoods is 200,000 pounds; though, it is indicated that stands on enriched habitats are considerably higher—to at least 250,000 pounds.

Volumes by habitat followed a different pattern than that of biomass. Whereas softwoods and hardwoods were similar in biomass production, softwoods were considerably more productive in both cubic feet and board feet. Softwood stands (including mixed wood stands with 24 percent softwood or more) supported significantly more cubic volume by age 70 to 90 or older than hardwoods growing on either hardwood habitats (numbers 8 to 10) or softwood habitats (numbers 2 to 7). Enriched stands were about equal to softwood stands in cubic volume (Fig. 13). In board-foot volume, softwood (including mixed wood) stands and hardwood stands on enriched habitats were much more productive than the other

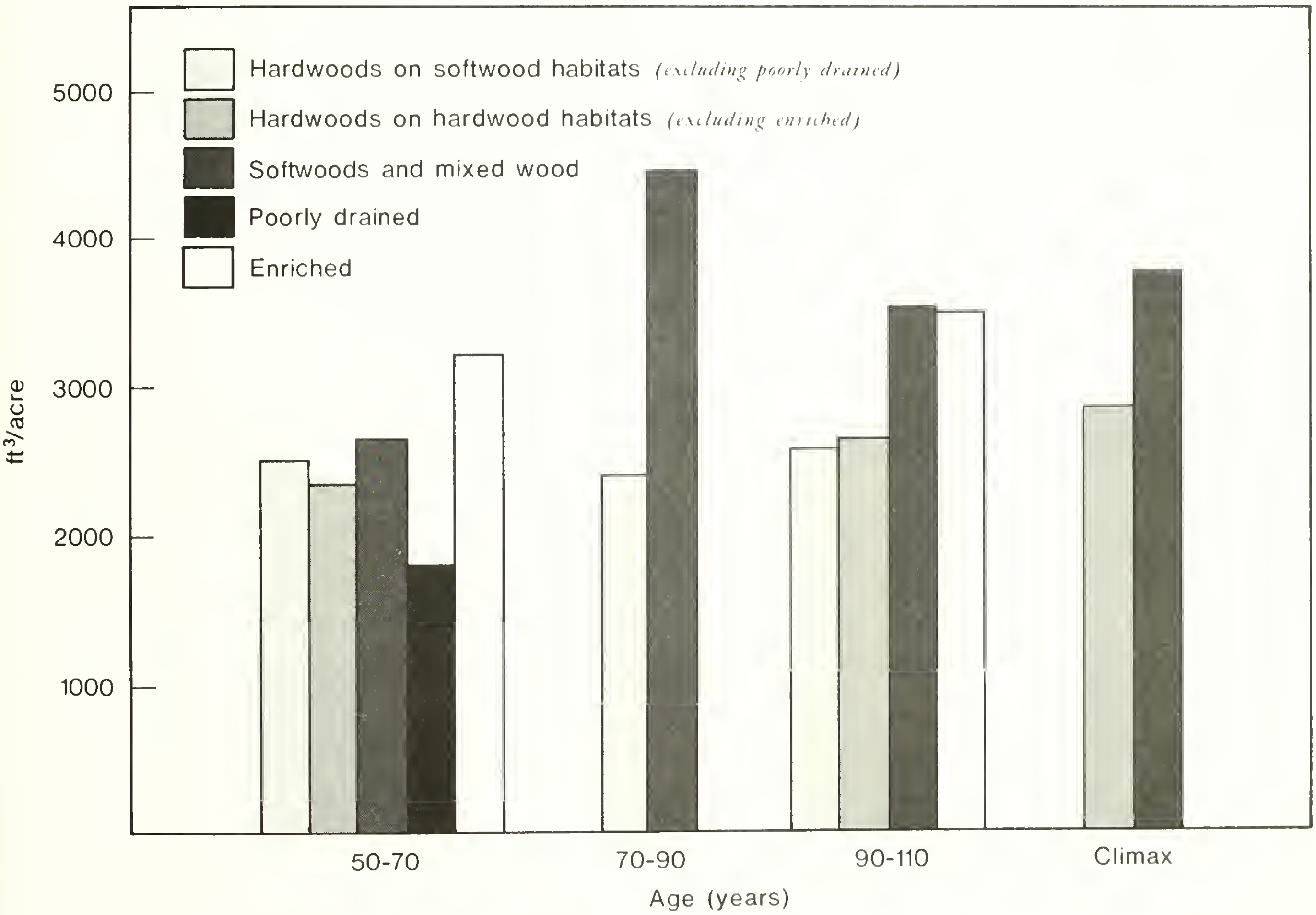

Figure 13.—Average cubic-foot volume per acre by habitat groups and stand age.

stands. Hardwoods growing on hardwood habitats produced more (40 percent at age 90 to 110) board-foot volume than the successional hardwoods found on softwood habitats (Fig. 14), though this difference was not significant.

Species Productivity

On the basis of past work (Leak 1978a), average site index by species and habitat apparently provides some basis for comparing the suitability of habitats for growing given species. Additional work in sapling and poletimber stands (Leak 1979) indicated that certain species differed among habitats in mean annual diameter growth.

In the present study on the Bartlett Forest, site index by species was extremely variable; only very demanding species such as white ash showed any noticeable trends in site index by habitat. Apparently, when an entire stand (rather than individual plots) is classified by habitat, there is substantial within-stand variation in site index.

The use of diameter-growth differences of unmanaged stands seemed to be a better possibility for evaluating species productivity. The use of mean diameter of all trees 1 inch dbh and larger did not work because diameter development was obscured by the small trees; even heavy sawtimber stands exhibited mean diameters of only 8 to 10 inches. Mean diameter of trees 8 inches dbh and larger provided a better indication of species development, but even with this measure there was high variability. Finally, I calculated average diameters of the largest trees per species, based on an average of one large tree per plot. For example, if we had seven plots in a stand, the average was based on the seven largest trees per species. Mean diameter was calculated by this method, corrected to a base age of 100 years,[3] and showed some reasonably distinctive differences among habitats (Table 7). However, none of these differences proved significant due to the small numbers of areas (samples) represented. Sugar maple and white ash grew best on the enriched habitats; mean diameters were 4 1/2 to 7 inches larger on the enriched habitat. Beech grew largest on well-drained sites such as the washed tills and sandy sediments. Red maple and paper birch grew fairly well on all habitats, a pattern that has been noted before (Leak 1979). Yellow birch did well on the enriched habitat, and tree sizes in the

[3] Corrected $\bar{D} = \frac{\bar{D} \times 100}{\text{stand age}}$

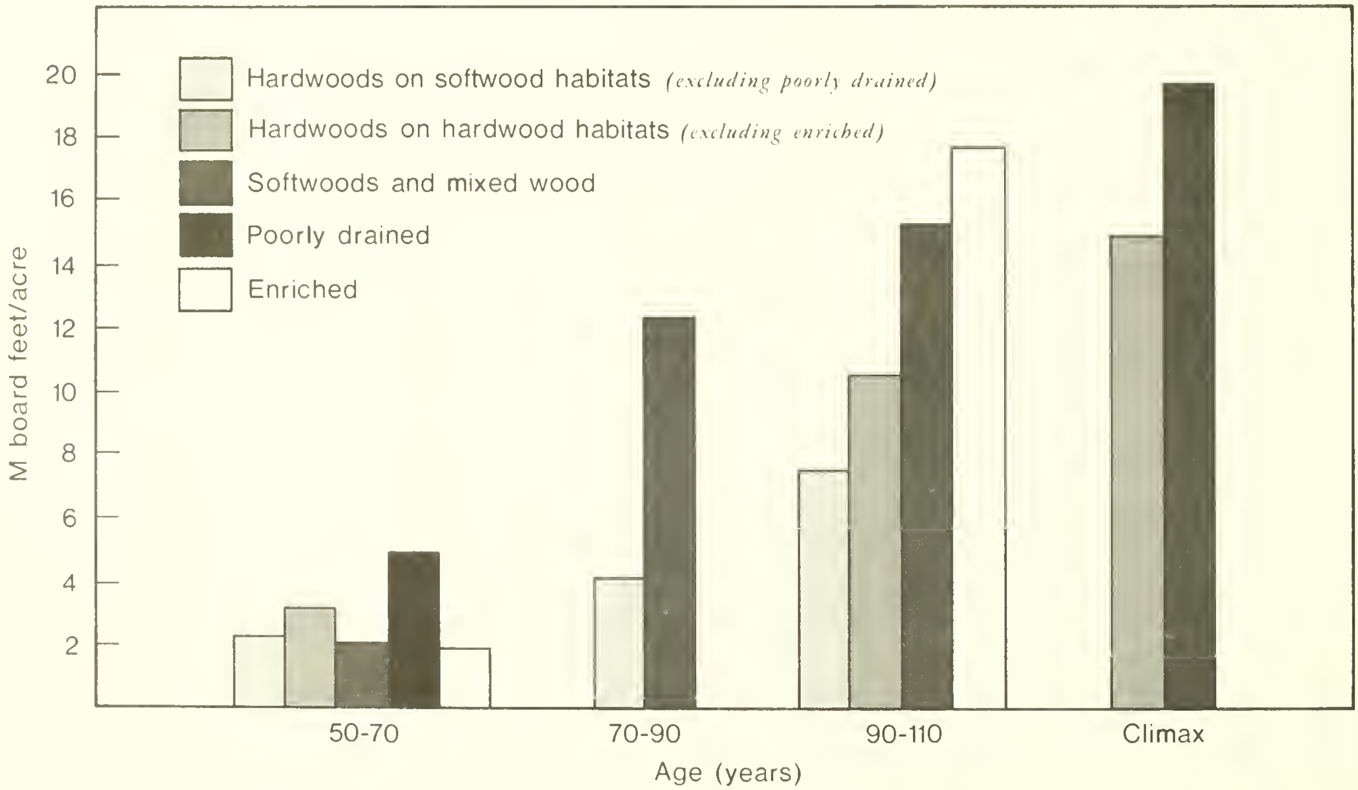

Figure 14.—Average board-foot volume per acre by habitat groups and stand age.

Table 7.—Mean diameter of largest trees (average of one tree per plot) at 100 years and in climax stands by species and habitat, in inches.

Habitat	Beech	Yellow birch	Sugar maple	Red maple	Paper birch	White ash	Red spruce	Eastern hemlock
				At 100 years				
Enriched(1)	—	17.3	19.6	—	—	21.1	—	—
Washed tills(9 and 8)	15.2	14.2	12.5	13.4	15.4	16.8	—	13.3
Sandy sediments(7)	14.8	—	—	17.0	13.6	—	—	—
Silty sediments(6)	12.0	12.6	—	16.9	—	—	—	22.2
Dry compact till(5)	12.5	12.0	9.6	14.6	13.8	—	—	—
Wet compact till(4)	9.8	11.2	9.4	16.8	14.3	16.0	14.8	18.6
Poorly drained(1)	—	—	—	—	—	—	13.6	—
				Climax				
Fine tills(10, 10C, 10S)	23.1	20.3	18.0	—	—	—	—	22.0
Silty sediments(6)	13.2	11.2	—	—	—	—	17.6	21.2
Outwash(3)	18.6	—	—	20.0	—	—	16.9	20.0
Bedrock(2)	—	—	—	—	10.0	—	18.3	25.7
Loose rock(2A)	14.0	14.3	—	17.7	—	—	14.0	21.3

climax stands indicate that this species also does well on fine till. Yellow birch performance on the washed tills was higher than expected, but perhaps because the fine washed till was predominant or present in all of these areas. Earlier work (1978a) indicated that site index of yellow birch was higher than that of paper birch on wet compact till, but that the reverse was true on dry compact till. However, the diameter information in Table 7 indicates that the compact tills are mediocre in comparison to the enriched sites and fine till for growing yellow birch.

Silvicultural Implications

The information presented so far on the relationship of habitat to species composition, stand productivity, and species performance provides some logical silvicultural implications for the Bartlett stands. These implications, which follow, are consistent with the general silvicultural directions previously defined for stands on granitic drift in the White Mountains (Leak 1980).

11. *Enriched*—This habitat is well-suited to the production of sugar maple and white ash sawlogs and veneer. Shelterwood seems the best regeneration technique for ash, and either shelterwood, selection, or group selection would be best for sugar maple. Early weedings or cleanings to favor increased proportions of these species should be economically worthwhile. These would be followed later by commercial thinnings. Cultural work around sugar maple should be light enough or delayed long enough so that low live branches are not abundant.

Paper and yellow birch also regenerate and grow well on these sites. Strips or small clearcuttings are the appropriate regeneration method. Openings should be small in low-lying or wet areas to prevent excess herbaceous growth and frost damage; logging or roading activity may need to be controlled on these wetter enriched sites during the spring.

10. 10C. 10S. *Fine till*—This habitat is well-suited to the production of northern hardwood sawtimber—sugar maple, yellow birch, and paper birch. Beech often will occupy up to 50 percent of the stand. Any regeneration method suited to the desired species is acceptable. Early cultural work should be economically worthwhile provided that it improves species or product potential. Roading and logging restrictions are minimal, except when fine till is underlaid by a compact layer (10C).

9. *Coarse washed till*—Beech is abundant and well formed on this habitat. Paper birch is capable of producing bolts and small to medium sawtimber. Although results are somewhat conflicting, I still favor paper birch over yellow birch based on both productivity and regeneration possibilities. Red maple is a much better possibility than sugar maple. Early cultural work directed toward increasing the proportion of paper birch should be economically acceptable. Roading and logging restrictions are minimal.

8. *Fine washed till*—This habitat has a potential similar to the coarse washed till. It could produce small to medium

sawtimber, bolts, and cordwood of primarily beech, red maple, and the birches. Yellow birch has a higher potential on this habitat than the previous one. Cultural work that favors increased proportions of birch with sawlog or boltwood potential should be worthwhile. Operating restrictions are minimal.

7. *Sandy sediments*—Softwoods (including hemlock, spruce, white pine, and some balsam fir) are the most productive on this habitat in terms of board- and cubic-foot volume. Because hardwoods often are abundant in successional stands, carefully designed shelterwood cuts probably would be needed to increase the softwood component. The best hardwood species are beech, red maple, and paper birch; yellow birch seems unproductive on these very well-drained materials. Hardwood product objectives should be fiber, boltwood, and small or lower-grade sawlogs. Cultural investments in young stands to increase the proportion of paper birch might be worthwhile. Operational constraints are minimal.

6. *Silty sediments*—Softwoods, especially hemlock and spruce, are more productive in board- and cubic-foot volume than the hardwoods. Hardwoods are abundant in successional stands and shelterwood systems may be needed to increase the softwood component. Paper birch, yellow birch, and red maple are moderately productive on this habitat. Beech is common but seems less productive here than on drier sites. These habitats may be too wet for logging or roading in early spring and after heavy rains.

5. *Dry compact till*—Softwoods again are the best volume producers. The best hardwoods are maple and paper birch; the logical product objectives are fiber, boltwood, and small or lower-grade sawlogs. Yellow birch seems less productive than paper birch on this habitat, though results are somewhat conflicting. Cultural efforts in young hardwoods should favor paper birch. Beech, though abundant, is not as productive here as on drier sites with unrestricted rooting. Operational problems often occur in spring and after heavy rains.

4. *Wet compact till*—Softwoods are most productive and usually are abundant. The best hardwoods are red maple, yellow birch, and paper birch; product objectives for hardwoods should be limited to fiber, bolts, and small to medium sawlogs. Cultural investments to increase the proportion of paper and yellow birch in young stands may be worthwhile. Operational problems are common, and this might limit logging and roading activities to winter.

3. *Outwash*—Softwoods are productive, and white pine is especially suitable on this habitat. The best hardwoods are red maple and paper birch; bolts, fiber, and small sawlogs are reasonable objectives. Cultural work in hardwoods should favor paper birch. Early cultural work to favor increased growth and sawlog production in white pine has economic potential. Operational problems are minimal.

2. *Shallow bedrock*—Despite the shallow soil, softwood stands on this habitat may have high cubic- and board-foot volume. The best hardwoods are red maple and paper birch; fiber and boltwood are the logical product objectives. Because of the shallow soils and difficulties in logging, I suggest minimal management effort: light selection or group selection cutting of the accessible areas to maintain the softwoods.

2A. *Loose rock*—Softwood stands again are more productive than hardwoods. Red maple and paper birch are the best hardwood species, although a few good yellow birch are found associated with waterways. Fiber, boltwood, and a few small sawlogs are logical hardwood products. Logging restrictions are minimal unless the slopes are steep. Cutting methods may include small clearcuttings or strip-cuttings for birch as well as selection and shelterwood cuttings.

1. *Poorly drained*—Softwoods are more productive than hardwoods. However, even softwood productivity in weight and volume is limited by excess water. I recommend minimal timber management: light selection or group selection cuttings during winter. Large openings may result in frost damage and herbaceous competition.

Applications

Approaches

Recognition of habitats such as those defined in this paper provides guidance on species to grow, regeneration cutting methods, potential productivity, and managerial constraints (problems with windthrow, logging, and roading). In the granitic areas of the southern White Mountains, the habitat definitions and interpretations in this publication should apply quite well. In other climatic/mineralogical zones, the definitions and interpretations will vary, and an effort will be required to develop and implement a habitat classification. Because of the great diversity that exists in New England in types of ownership and objectives of management, the effort will vary in intensity and detail. At least three approaches are possible depending upon the expertise and resources available.

1. *Biophysical classification*—Map a forest property (or the commercial forest land) into habitats or land types based on landform, vegetation, and soil materials. A small-scale map can be prepared for planning purposes, and it can be used with a more detailed map for project work. This approach requires both soils/geologic and botanical skills. A considerable amount of reconnaissance or plot work will be required to develop the habitat taxonomy and mapping criteria.

2. *Forest type classification*—Evaluation of stand potential may be based on forest type alone. The types listed in Table 1 provide a reasonable starting point because our work has already indicated that they are common species associations that sometimes reflect differences in site. However, the main limitations on the use of forest types alone are (1) lack of information on operability, and (2) differences that are not site related and cannot be readily duplicated because of past cutting history and other types of disturbances.

   This approach can be slightly refined through an assessment of soil moisture adequacy (Table 1). This soil moisture assessment provides a sharper definition of species suitability and operational constraints.

   Both approaches can be applied either through mapping of the forest property or by evaluating each stand as it is scheduled for silvicultural treatment.

3. *Forest type/forest soils classification*—If soils maps are available, they can be used as a starting basis for assessing habitat conditions. This approach can be undertaken as a mapping project or as a means to assess stands scheduled for silvicultural treatment. With a soils map in hand, a reconnaissance of the property will show how forest types such as those in Table 1 change in relation to changes in soil types or associations. Concentrate on fairly significant changes in forest type: valuable hardwoods, less valuable hardwoods, mixed woods, and softwood. And, it may be necessary to subdivide or lump soils units to reflect important change in forest condition.

   Notes should be taken on species and condition of overstory and understory; estimates of stocking and site index also can be taken if time warrants. Soils limitations are available from the soils map interpretations. Given this information, a forester can recognize and list the major soils-vegetation associations and develop logical interpretations on: species to favor, cutting methods to regenerate favored species, potential problems with competition from weeds, trees and shrubs, areas suited to intensive management, wildlife considerations, and limitations on roading and logging.

Agricultural Areas

The classification of habitat conditions in areas disturbed by agriculture requires special consideration because the vegetation often is different than usual. Old-field or pastured stands frequently contain more white pine, spruce, or hemlock than would usually be found on a given soil material. In evaluating such areas, the composition and quality of the existing vegetation can be used as a guide on how to treat the present stand. However, regeneration cutting practices should be based on an evaluation of soil materials and understory tree vegetation. It seems that such disturbed areas will begin to revert to the natural forest vegetation by the second rotation. For example, old-field white pine growing on a hardwood site will seldom regenerate successfully or easily to white pine because of hardwood competition.

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List of Species

Scientific name	*Common name*
Trees:	
Abies balsamea (L.) Mill.	Balsam fir
Acer rubrum L.	Red maple
Acer saccharum Marsh.	Sugar maple
Betula alleghaniensis Britton	Yellow birch
Betula papyrifera Marsh.	Paper birch
Fagus grandifolia Ehrh.	American beech
Fraxinus americana L.	White ash
Picea rubens Sarg.	Red spruce
Pinus strobus L.	White pine
Tsuga canadensis (L.) Carr.	Eastern hemlock
Shrubs and small trees:	
Acer pensylvanicum L.	Striped maple
Gaultheria procumbens L.	Wintergreen
Kalmia angustifolia L.	Sheep laurel
Taxus canadensis Marsh.	Canada yew
Vaccinium angustifolium Ait.	Low, sweet blueberry
Viburnum alnifolium Marsh.	Hobblebush
Viburnum cassinoides L.	Wild raisin
Herbs:	
Aralia nudicaulis L.	Sarsaparilla
Clintonia borealis (Ait.) Raf.	Clintonia
Coptis groenlandica (Oeder) Fern.	Goldthread
Cypripedium acaule Ait.	Moccasin-flower
Dryopteris spinulosa (O. F. Muell.) Watt.	Woodfern
Lycopodium annotinum L.	Clubmoss
clavatum L.	
lucidulum Michx.	
Maianthemum canadense Desf.	Wild lily-of-the-valley
Medeola virginiana L.	Indian cucumber
Oxalis montana Raf.	Wood sorrel
Trientalis borealis Raf.	Starflower
Trillium erectum L.	Trillium
undulatum Willd.	
Uvularia sessilifolia L.	Wild oats
Sphagnum spp.	Sphagnum

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Recommendations are given on the classification of forest land in New England on the basis of physiographic region, climate (elevation, latitude), mineralogy, and habitat. A habitat map for the Bartlett Experimental Forest in New Hampshire is presented based on landform, vegetation, and soil materials. For each habitat or group of habitats, data are presented on stand composition, understory vegetation, biomass, volume, and diameter development by species.

ODC: 182.22:114.33

Keywords: land classification, site, soils, northern hardwoods.

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The Effect of Changes in Lumber and Furniture Prices on Wood Furniture Manufacturers' Lumber Usage

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Abstract

Wood furniture manufacturers' demands for oak, maple, poplar, open-grain, and close-grain lumber are estimated using cross-sectional, time-series techniques. The analyses indicate that the demand for open-grain species is more price responsive than the demand for close-grain species. The calculated cross-price elasticities indicate that furniture producers do substitute species through style decisions. However, poplar lumber has a negative cross-price elasticity, indicating that it is used with, rather than substituted for, other species.

Introduction

Wood furniture manufacturers are the major demanders of higher grade hardwood lumber; they use more than 24 percent of all hardwood lumber consumed in the United States. Because furniture demand is expected to increase as the "baby boom" generation establishes new households, demand for hardwood lumber by wood furniture manufacturers is expected to increase. This could lead to significantly increased lumber prices if current conditions in the hardwood lumber market persist.

One major problem within the hardwood lumber market is lack of information on the inner workings of the market itself. Inadequate information makes markets inefficient because productive resources tend to be poorly allocated. Poor allocation of productive resources increases production costs and leads to increased consumer prices. The objective of this study is to provide some of this much needed information by quantifying the relationship between furniture manufacturers' demand for hardwood lumber and the prices of hardwood lumber and furniture.

Such information would benefit lumber distributors, the furniture industry, and furniture consumers. Lumber distributors (producers and wholesalers) could use such information to better anticipate current and future demands for various species of hardwood lumber. The furniture industry would benefit from the actions of lumber distributors because adequate supplies would more likely be available at the time they are needed. Consumers would benefit from the eventual decrease in the relative price of furniture.

Model Development

Wood furniture manufacturers use many different species of hardwood lumber. The amount of a particular species used by a manufacturer is dependent on the price category and style of furniture being produced and the price of furniture in general. The price of one species may affect the demand for, or usage of, another species because of the relationship between past lumber prices and current styles being introduced at the furniture markets. Of course, this relationship is much weaker for a manufacturer specializing in high-priced 18th century reproductions than for a manufacturer producing several lines of popular-priced furniture.

In this study, the quantity of hardwood lumber of a particular species demanded by a furniture manufacturer is assumed to be affected by: (1) the past prices of lumber of that species (own price), (2) the past prices of complementary and substitute species (cross price), (3) the wholesale price of furniture and (4) past quantity of lumber demanded.

Lagged quantity is included in the model as an aggregation variable. This allows the demands of firms of various sizes to be estimated in the same equation. This variable also accounts for style expectations, since past lumber use is representative of past furniture styles produced by the firm.

The major variables included in the general model and the expected relationships between the variables and the quantity demanded are specified in Table 1. This general specification is the basis for all estimated demand equations presented in the next section.

Table 1.—The major factors, variables, expected relationships between variables and quantity demanded, and units for furniture manufacturers' lumber demand equations

Factor	Variable	Expected relation	Units
Lumber price of the species being demanded	Price index of lumber of the species being demanded, lagged 1-1/2 years (own price)	Negative	Index (1974 = 100)
Lumber price of substitute or complementary species	Weighted price index of substitute or complementary species, lagged 1-1/2 years (price of substitutes, complements)	Positive (substitute) Negative (complement)	Index (1974 = 100)
Wholesale price of wood furniture	An index of the wholesale price of furniture (furniture price)	Positive	Index (1967 = 100)
Lagged quantity	Quantity of lumber of the species being demanded, lagged 1 year (lagged quantity)	Positive	Million board feet

Specification of Substitute and Complement Price Variables

Since each estimated equation represents the demand by furniture manufacturers for a specific species of lumber, the variable representing the price of substitutes or complementary species is different for each equation. The variable representing the price of substitute species in the oak equation is the weighted price index of ash, pecan, elm, hackberry, maple, and white pine lumber. These species have some characteristics that may encourage a manufacturer to use them, rather than oak, when designing a suite. The first four species are chosen because they have an open grain. Maple is included because it and oak are intermediate-priced species. White pine is included because it is a substitue for oak in heavy, "over designed" furniture.

The variable representing price of substitute lumber in the maple equation is the weighted price index of cherry, gum, and oak lumber. It is felt that these species have certain characteristics that allow them to be substituted for maple. Cherry and gum are close-grain species with some characteristics similar to maple lumber, while both oak and maple are intermediately priced.

The cross-price variable for open-grain lumber contains the weighted price index of all lumber not considered open grain. While the price of substitute lumber in the close-grain equation is the weighted price index of all non-close grain lumber, no cross-price variable is included in the demand for all lumber because the weighted price of all species of lumber is included in the own-price variable.

The weighted price index of all species other than poplar is used as the price of complements in the poplar demand model. We assume that poplar is used with, rather than substituted for, other species of lumber. It should be noted that the data base for the poplar demand equation does not contain any promotional furniture producers. Promotional furniture producers use poplar in exterior parts and may substitute poplar lumber for sweet gum, black gum, or other inexpensive woods that can be easily embossed.

Data Base

The quantity data used in this paper were originally collected for a study of wood furniture manufacturers' demands by Luppold (1981). These data consist of lumber usage statistics, by species, for the years 1974 through 1979 by 11 wood furniture producers. These producers employed 250 or more production workers each and were located in Virginia, North Carolina, and South Carolina. All firms included in the final sample produced several different lines of furniture and used several different species of hardwood lumber. Lumber price data were obtained from the *Hardwood Market Report* (Lemsky 1972–1978) and wood furniture price data were collected from *Wholesale Prices and Price Indexes* (U.S. Department of Labor 1974–1979).

The firms included in the data base are representative of the larger wood furniture manufacturers in the Southeast. Wood furniture firms in this region account for more than 50 percent of the national production, and firms employing 250 or more workers account for about 75 percent of the materials used in wood furniture manufacturing (U.S. Department of Commerce 1980).

Equation Estimation

Demand relationships were estimated for oak, maple, and poplar lumber, as well as for open-grain lumber, close-grain lumber, and all lumber as an aggregate. These estimated relationships are presented and compared in this section.

Since the data base consists of lumber usage over time by several firms, the equations were estimated by the ordinary least squares (OLS) and cross-sectional time-series (CSTS) techniques. Results from both estimation procedures are presented to show the advantages and disadvantages of each technique. The Parks (1967) cross-sectional time-series algorithm was used because it accounts for contemporaneously correlated errors between cross sections that may result from the omission of unknown or unmeasurable variables. The Parks method also adjusts for autocorrelation within time series and heteroskedasticity across cross sections. A rigorous development of the Parks method is presented in the Appendix.

Because pooled cross-sectional and time-series data are used, estimated responses to changes in prices (price elasticities) cannot be strictly interpreted as being either longrun or shortrun in nature. However, since there was much more variation in the prices over time than there was over the firms, the resulting elasticities are more representative of shortrun responses.

The results of the OLS estimates are presented in Table 2, while the CSTS estimates are presented in Table 3. The standard errors associated with almost all the parameters are reduced by as much as 94 percent by using the Parks estimation procedure. Further, the magnitudes of the coefficients do not differ significantly between the OLS estimates and the CSTS estimates except for the maple model. The decrease in standard error without a radical change in the magnitude of the estimated coefficients indicates that the Parks method did yield statistically more efficient estimates than did OLS.

Table 2.—Ordinary least squares estimates of wood furniture manufacturers' demand for hardwood lumber, by species, 1975-1979 (standard errors in parentheses)

	Oak lumber	Maple lumber	Poplar lumber	Open grain lumber	Close grain lumber	All lumber
Intercept	– 3832	– 2318	– 1487	– 3124	– 3140[d]	– 5337
	(3139)	(3254)	(2137)	(4032)	(2929)	(5737)
Own price	– 32.61[d]	79.24	– 8.56	– 38.02[d]	– 5.47	– 15.66
	(26.86)	(60.72)	(13.98)	(34.60)	(5.01)	(60.54)
Price of substitutes and complements	59.64[a]	– .628	– 11.64	23.19	– .218	NA
	(22.91)	(13.67)	(18.64)	(35.34)	(20.98)	
Price of furniture	5.03	– 1.43	20.9[c]	27.3	23.6[c]	44.0[d]
	(29.1)	(24.6)	(14.8)	(27.8)	(18.1)	(32.6)
Lagged quantity	.857[a]	.816[a]	1.006[a]	.959[a]	.963[a]	.967
	(.065)	(.179)	(.039)	(.043)	(.062)	(.032)
R^2	.905	.599	.954	.935	.911	.958
F-value	59.6	7.50	183	127	64.4	309
Degrees of freedom	25	20	35	35	25	40
Mean quantity (Mbf)	5470	1590	3300	7669	3224	16148

a = Significant at the .01 level.
b = Significant at the .05 level.
c = Significant at the .10 level.
d = Significant at the .15 level.
NA = Not applicable.

Table 3.—Cross-sectional time-series results of wood furniture manufacturers' demand for hardwood lumber, 1975-1979 (standard errors in parentheses)

	Oak lumber	Maple lumber	Poplar lumber	Open grain lumber	Close grain lumber	All lumber
Intercept	– 3398[a]	– 902[c]	1896[b]	– 4219[a]	– 3096[a]	– 6569[a]
	(821)	(681)	(1051)	(861)	(934)	(1400)
Own price	– 35.80[a]	– 12.82[b]	– 11.63[b]	– 39.31[a]	– 6.27[a]	– 15.66[a]
	(6.58)	(6.38)	(5.88)	(5.75)	(.854)	(3.52)
Price of substitutes and complements	35.76[a]	2.56[b]	– 8.49[b]	40.96[a]	7.76[b]	NA
	(8.14)	(1.44)	(4.35)	(6.85)	(4.14)	
Price of furniture	17.4[a]	13.2[a]	22.7[a]	23.6[a]	20.3[a]	45.8[a]
	(4.78)	(4.75)	(5.12)	(5.10)	(6.29)	(11.8)
Lagged quantity	.941[a]	.964[a]	1.024[a]	1.01[a]	.898[a]	.994[a]
	(.019)	(.058)	(.048)	(.011)	(.070)	(.006)
Degrees of freedom	25	20	35	35	25	40
Mean quantity (Mbf)	5470	1590	3300	7669	3224	16148

a = Significant at the .01 level.
b = Significant at the .05 level.
c = Significant at the .10 level.
d = Significant at the .15 level.
NA = Not applicable.

Interpreting the Results

The effect of changes in lumber or furniture price on quantity of lumber demanded is exhibited in Table 4 in the form of price elasticities. These elasticities indicate the percentage change in quantity demanded resulting from a 1-percent change in price. Own-price elasticity represents the effect of a change in price of a particular species on the demand for that species, while cross-price elasticity represents the effect of a change in prices of other species.

As previously mentioned, the elasticities are more representative of shortrun responses to changes in prices, since most of the variation in the data base occurred in the time-series data rather than in the cross-sectional data. Since furniture producers respond to past lumber prices and current furniture price, the estimated lumber-price elasticities are indicative of the likely response 1 to 2 years after a change in lumber price, and the furniture-price elasticity represents the response in the current year to a change in furniture price.

In general, open-grain lumber was found to be more price-elastic with respect to its own price and the price of substitutes, and less price elastic with respect to furniture price than was close-grain lumber. One exception to this rule was maple, which had the highest own-price elasticity and the lowest furniture-price elasticity. These results indicate that open-grain lumber demand is more affected by lumber price and close-grain lumber demand is more affected by furniture price.

Another general observation that can be made is that the cross-price elasticities are nearly as high or higher than the own-price elasticities in the oak, open-grain, close-grain, and poplar equations. This indicates that prices of other lumber, when taken as a group, affect demand for a particular species by about the same amount as the price of that species. Again, one exception to this rule is maple, which appears to have a very low cross-price elasticity.

The estimated cross-price elasticity of poplar is negative. This finding supports the hypothesis that poplar is a complement to other lumber and not a substitute. The low own-price elasticity was also expected, since poplar is used as an interior lumber with a number of different exterior species.

The own-price elasticity for all lumber demanded is −.09, which is quite low. This is not surprising since wood furniture manufacturers must use wood. The furniture-price elasticity of .49 is also quite low when compared with the demand equations for the different species.

The elasticities calculated from the estimated maple demand equation are much different for the elasticities of the other equations. These results may be due to some peculiar characteristics of maple, but also may result from the relatively poor statistical fit of the maple equation. The OLS estimates for the maple equation had a low R^2 and incorrect signs for three of the four nonintercept variables. Although the CSTS results had the correct signs on all variables, the standard errors associated with the estimated parameters were relatively high.

Table 4.—Own-price, cross-price, and furniture-price elasticities for wood furniture manufacturers' demand for hardwood lumber, 1975–1979

Model	Own-price elasticity[a]	Cross-price elasticity	Furniture-price elasticity
Oak lumber	−.654	.743	.550
Maple lumber	−.867	.171	.143
Poplar lumber	−.295	−.282	1.18
Open-grain lumber	−.525	.566	.528
Close-grain lumber	−.265	.243	1.08
All lumber	−.087	NA	.488

[a] All elasticities were calculated at the means using the cross-sectional time-series parameter estimates, by the following formula:

$$\frac{\partial \text{ quantity demanded}}{\partial \text{ price}} \times \frac{\text{(mean of price)}}{\text{(mean of quantity demanded)}}$$

NA = Not applicable.

Implications

Two major implications of this study are: (1) past lumber and current furniture prices affect wood furniture manufacturers' demand for lumber, and (2) current demand for a particular species is affected by past prices of other species. With respect to the second implication, it should be noted that most furniture manufacturers do not directly substitute one species for another; rather, past lumber prices affect current design and style decisions. The degree to which past lumber prices affect current design varies from firm to firm. But the sizes of the estimated cross-price elasticities relative to the own-price elasticities indicate that large firms do consider past lumber prices when developing and promoting different styles of furniture.

Another implication is that wood furniture manufacturers' demand for hardwood lumber, as a whole, is quite inelastic with respect to the price of hardwood lumber. However, these manufacturers' demand for lumber of specific species or groups of species is much more elastic. Of the individual species and species groups, open-grain, oak, and maple lumber are more price-elastic than poplar and close-grain lumber.

Furniture manufacturers' demand for close-grain lumber is relatively inelastic with respect to the price of close-grain lumber and the price of substitute species, but is relatively elastic with respect to price of furniture. These results indicate that the demand for species used in traditional types of furniture, such as cherry and mahogany, is not greatly affected by the prices of substitute species, but is influenced by the price of wood furniture.

Maple lumber demand is different from the demand for other close-grain species in that maple demand is relatively price-elastic. However, demand for maple lumber is similar to the demand for close-grain species in that cross-price elasticity is relatively low and furniture-price elasticity is relatively high. These results may suggest that maple lumber demand is greatly affected by the price of maple lumber and the price of wood furniture, but these results must be interpreted with caution since the statistical fit of this equation was relatively poor.

The estimated results of the demand for open-grain lumber indicate little difference between own-price elasticity, cross-price elasticity, and furniture-price elasticity. This indicates that the price of open-grain lumber, the price of substitute species, and the price of furniture have about an equal effect on the demand for open-grain species.

Oak lumber demand is different from the demand for all open-grain species in that the absolute values of the cross-price and own-price elasticities are up to 35 percent larger than the furniture-price elasticity. However, the furniture-price elasticity for oak is very close to the furniture-price elasticity for all open-grain species. These results imply that the demand for oak lumber is more responsive to changes in the price of oak and other species than it is to changes in the price of furniture.

The estimated demand for poplar lumber indicates a relatively inelastic own-price elasticity and a relatively elastic furniture-price elasticity. The negative cross-price elasticity indicates that poplar lumber is used in conjunction with, rather than as a substitute for, lumber of other species. The results also indicate that poplar lumber demand is elastic with respect to the price of wood furniture.

Summary and Conclusions

Furniture manufacturers are the major demanders of higher grade hardwood lumber. Their demands are expected to increase in the future because of an expected increase in furniture demand. Increased lumber demand will inevitably lead to increased lumber price. The level lumber price will reach is uncertain since many factors affect it; however, increasing the efficiency of the hardwood lumber market would help to keep future price increases at a minimum.

One major ingredient of market efficiency is good market information. The objective of this study was to provide some of the needed information by developing and estimating relationships that measure the effect of lumber and furniture prices on wood furniture manufacturers' demand for lumber.

Equations representing furniture manufacturers' demands for oak, maple, poplar, open-grain, close-grain, and all varieties of lumber were estimated using OLS and CSTS techniques. The results indicate that wood furniture manufacturers do substitute species to reduce costs; but this substitution takes place over time and not immediately. Such substitutions will cause fluctuations in the prices of individual species rather than in the aggregate price of hardwood lumber.

Future analysis using cross-sectional time-series data from more firms and in separate regions would provide greater and more refined information on wood furniture manufacturers' lumber demands. Information pertaining to the substitution of other wood products and nonwood products for lumber would also be of great value in predicting future market behavior.

In conclusion, wood furniture manufacturers' demand for lumber of various species is price-sensitive. Lumber distributors should realize this before making long run commitments. Forest industry groups and policymakers should also realize the degree to which one species can substitute for another before advocating legislation aimed at ensuring adequate domestic supplies of any particular species.

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Appendix

The Parks Method of Cross-Sectional Time-Series Estimation

When equations are estimated with ordinary least squares and pooled cross-sectional and time-series data, the resulting parameter estimates are unbiased and consistent. However, these estimates may be inefficient because of the effects of autocorrelation and heteroskedasticity. The Parks method is an Aitken's generalized least square procedure that incorporates prior information of the disturbance term in the estimation of the parameters. The resulting parameter estimates have the properties of consistency, unbiasedness, asymptotic efficiency, and asymptotic normality.

The general form of a statistical model containing k variables and using pooled cross-sectional and time-series data can be expressed as:

$$Y_{it} = B_0 + B_1X_{it,1} + \ldots + B_kX_{it,k} + \varepsilon_{it} \qquad [1]$$

$$(i = 1, \ldots, N)\ (t = 1, \ldots, T)$$

The sample data are represented by T time-series and N cross-sectional observations for a total of N × T observations. The statistical model can be expressed in matrix notation as follows:

$$Y = XB + \varepsilon \qquad [2]$$

Where Y is an (N × T) × 1 vector of observations of the dependent variable, X is an (N × T) × (k + 1) matrix of observations of predetermined variables, B is a (k + 1) × 1 vector of parameters and ε is an (N × T) × 1 vector of disturbance terms. The ordinary least squares estimates for the model are:

$$B = (X'X)^{-1} X'Y \qquad [3]$$

Given the general model, the following assumptions are made:

(i) $E(\varepsilon, \varepsilon^1) = \Omega$, where:

$$\Omega = \begin{bmatrix} E(\varepsilon_{11}^2) & \ldots & E(\varepsilon_{11}\varepsilon_{IT}) & \ldots & E(\varepsilon_{11}\varepsilon_{N1}) & \ldots & E(\varepsilon_{11}\varepsilon_{NT}) \\ \vdots & & \vdots & & \vdots & & \vdots \\ E(\varepsilon_{IT}\varepsilon_{11}) & \ldots & E(\varepsilon_{IT}^2) & \ldots & E(\varepsilon_{IT}\varepsilon_{N1}) & \ldots & E(\varepsilon_{N1}\varepsilon_{NR}) \\ \vdots & & \vdots & & \vdots & & \vdots \\ E(\varepsilon_{N1}\varepsilon_{11}) & \ldots & E(\varepsilon_{NT}\varepsilon_{IT}) & \ldots & E(\varepsilon_{N1}^2) & \ldots & E(\varepsilon_{N1}\varepsilon_{NT}) \\ \vdots & & \vdots & & \vdots & & \vdots \\ E(\varepsilon_{NT}\varepsilon_{11}) & \ldots & E(\varepsilon_{NT}\varepsilon_{IT}) & \ldots & E(\varepsilon_{NT}\varepsilon_{N1}) & \ldots & E(\varepsilon_{NT}^2) \end{bmatrix}$$

$$(N \times T) \times (N \times T)$$

(ii) the predetermined variables are nonstochastic and are independent of the disturbance term.

(iii) the number of observations exceeds the number of predetermined variables plus the intercept.

The specification of the behavior of the disturbance term for models estimated using time-series data pooled cross-section and time-series is:

(i) $E(\varepsilon_{it}^2) = \sigma_{ii}$

(ii) $E(\varepsilon_{it}\varepsilon_{jt}) = \sigma_{ij}$

(iii) $\varepsilon_{it} = \rho_i\varepsilon_{i,t-1} + \mu_{it}$

where:

$$\mu_{it} \sim N(0, \phi_{ii})$$

$$E(\varepsilon_{i,t-1}\mu_{jt}) = 0 \text{ for all } i, j$$

$$E(\mu_{it}, \mu_{jt}) = \phi_{ij}(i \neq j)$$

$$E(\mu_{it}, \mu_{js}) = 0(t \neq s)$$

$$i, j = 1, \ldots, N$$

$$t, s = 1, \ldots, T$$

Condition (i) allows cross-sectional heteroskedasticity, condition (ii) allows mutual correlation of the disturbance term across cross sections and, condition (iii) permits a separate first-order autoregression scheme for each cross section. The autoregressive disturbance term, μ_{it}, is assumed to be normally distributed with a constant variance and zero covariance between time periods for the same cross-sectional unit (furniture firm). The autoregressive disturbances during the same time period are correlated across cross sections, but the autoregressive disturbance for firm i, in period t, and firm j, in period s, for s = t are assumed to be independent. Finally, $\varepsilon_{i,t-1}$, and μ_{jt} are assumed to be independent.

Given the specification of the behavior of the disturbance term, the following relationships can be developed:

(i) $E(\varepsilon_{it}^2) = \phi_{ii}/1 - P_i^2 = \sigma_{ii}$

(ii) $E(\varepsilon_{it}\varepsilon_{jt}) = \phi_{ij}/1 - \rho_i \rho_j = \sigma_{ij}$

(iii) $E(\varepsilon_{it}\varepsilon_{is}) = \rho_i^{t-s}\sigma_{ii}$ if t is greater than s

(iv) $E(\varepsilon_{it}, \varepsilon_{js}) = \rho_i^{t-s}\sigma_{ij}$ $(i = j)$

$$i,j = 1, \ldots, N$$

$$t,s = 1, \ldots, T$$

The initial disturbance term, ε, associated with the pooled cross-sectional time-series data is assumed to have the following properties:

$$\varepsilon_{ia} \sim N(0, \phi_{ii}/1 - \rho_i^2)$$

$$E(\varepsilon_{ia}\varepsilon_{ja}) = \phi_{ij}/1 - \rho_i \rho_j$$

The matrix for the Parks model is:

$$\Omega = \begin{bmatrix} \sigma_{11}P_{11} & \ldots & \sigma_{1N}P_{1N} \\ \sigma_{N1}P_{N1} & \ldots & \sigma_{NN}P_{NN} \end{bmatrix}$$

$$(N \times T) \times (N \times T)$$

where:

$$P_{ij} = \begin{bmatrix} 1 & \rho j & \ldots & \rho^{T-1} \\ \rho_i & 1 & \ldots & \rho_j^{T-2} \\ \rho_i^{T-1} & \rho_i^{T-2} & \ldots & 1 \end{bmatrix}$$

$$(T \times T)$$

The Parks method estimates an Ω matrix by first estimating a value for ρ_i from an ordinary least square estimate. Using ordinary least squares, the following equation is estimated:

$$Y_{it}^* = B_0^* + B_1^* X_{1t}^* + \ldots + B_k^* X_{it}^* + \mu_{it}^* \qquad [4]$$

where:

$$Y_{it}^* = Y_{it} - \rho_i Y_{i,t-1}$$

$$X_{it,k}^* = X_{it,k} - \rho_i X_{i,t-1,k} (k = 1, \ldots, k)$$

$$B_0^* = B_0(1 - \rho_i)$$

$$\mu_{it}^* = \varepsilon_{it} - \rho_i \varepsilon_{i,t-1}$$

$$t = 2, \ldots, T$$

$$i = 1, \ldots, N$$

From the residuals of the above estimation, μ_{it}^* is calculated.

From these residuals, estimates of ϕ_{ii}, ϕ_{ij}, σ_{ii}, and σ_{ij} are obtained by:

$$\phi_{ii} = (1/T - k - 1) \Sigma \mu_{it}^{*2}$$

$$\phi_{ij} = (1/T - k - 1) \Sigma \mu_{it}^* \mu_{jr}^*$$

$$\sigma_{ii} = \sigma_{ii}/1 - \rho_i^2$$

$$\sigma_{ij} = \phi_{ij}/1 - \rho_i \rho_j$$

This procedure yields consistent estimates of σ_{ii} and σ_{ij}, therefore, a consistent estimate of Ω is obtained. Finally, using the Aitken's procedure,

$$B = (X'\tilde{\Omega}^{-1}X)^{-1} (X\Omega^{-1}Y) \qquad [5]$$

where $\tilde{\Omega}$ is a consistent estimator for Ω. The asymptotic variance-covariance matrix of B is:

$$\text{Var-Cov } (B) = (X'\tilde{\Omega}^{-1}X)^{-1} \qquad [6]$$

Luppold, William G. **The effect of changes in lumber and furniture prices on wood furniture manufacturers' lumber usage.** Res. Pap. NE-514. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 8 p.

Wood furniture manufacturers' demands for oak, maple, poplar, open-grain, close-grain, and all species of lumber were developed using cross-sectional time-series estimation techniques.

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A Classification System for Predicting Pallet Part Quality from Hardwood Cants

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Abstract

Producers who manufacture pallet parts from hardwood cants generally must purchase cants on the basis of existing structural timber grades that do not adequately reflect the quality of pallet parts produced from resawed cants. A system for classifying cants for pallet part production has been developed that more accurately reflects the parts grade mix that can be produced from each of the new cant classes. A formula is given to determine value relatives for each cant class.

Introduction

The early practice of the pallet industry for procuring hardwood raw material was to purchase stringer stock (mostly 2 by 4's) and low-grade random lumber for deckboards from sawmills. As the industry developed, this practice changed to the purchase of cants or lumber of specified dimensions, in multiples of sizes required for individual pallet parts. This material was then resawed into pallet parts.

In 1958 the National Wooden Pallet and Manufacturers Association (now the National Wooden Pallet & Container Association) published specifications which included a pallet and parts grading system that reflected the degree of strength and durability of four grades of commercial pallets. The pallet grades were based on the placement of various grades of parts in the pallet. The parts grades were based on the size, type, and distribution of defects that affect the strength and durability of the part.

Although this system provided a method of assuring overall pallet quality and performance, it did not include a method of predicting pallet part grade yield from cants. Existing structural cant grades (National Hardwood Lumber Association [NHLA] Rules) were developed for application to whole pieces; they were not intended to reflect the grade mix of parts resawed from the pieces. For the last 15 years, pallets have been produced by specifying the minimum quality of parts acceptable in the pallet. As a result, pallet producers who do not have markets for a variety of pallet grades develop surplus inventories of off-grade parts.

To help alleviate this situation, we experimented with a cant classification system (Interim) that is based on the same defect size, type, and distribution as the National Wooden Pallet & Container Association (NWPCA) parts grading rules (Appendix). This system enables a pallet producer to purchase grade classes of cants that will yield the grade mix of parts that more nearly meet the requirements for his operation, and thus help minimize the accumulation of off-grade parts.

This paper describes the system of classifying cants for pallet part production and provides the grade mix of parts produced from each cant class. It also compares the newly developed cant classes with two construction timber grades from NHLA rules and one grade used by some industry firms (Appendix). In this report, the latter three grades are referred to as "Present."

Procedure

Four- and six-foot-long bolts from each of three species groups (yellow-poplar—cucumber, birch—maple, and red—white—chestnut oak) were sawed into 4- by 4-inch and 4- by 6-inch cants. The cant width was dictated by the size of the bolt. No effort was made to balance the cant widths produced.

Bolts were processed until a minimum of 10 cants were produced for each of four cant classes in each length category and for each species group. The cant classes were developed from the NWPCA grading rules for industrial pallets. Each cant also was graded by specifications by Present rules.

Each cant was sawed into 1- by 4-inch pallet deckboards and 2- by 4-inch pallet stringers. The pallet parts were classified by a grading system based on the NWPCA pallet grading rules.

Results

A total of 295 cants were processed into parts. The cant distribution by classes was:

Classification system	Cant class			
	1	2	3	Below grade
	percent			
Interim	33	23	24	20
Present	24	66	5	5

Graded pallet part yields by interim cant classes were:

Cant class interim	Part grade yield (NWPCA)			
	1	2	3	Below grade
	percent			
1	59	23	8	10
2	33	23	29	15
3	10	19	37	34
Below grade	10	11	14	65

(See Table 1 for grade yields by species and length.)

Table 1.—Parts yields by NWPCA grades from cants classified by the interim grading system, in percent

Species	Interim cant class	Number of samples	Parts grade 1	Parts grade 2	Parts grade 3	Parts grade Below grade	Number of samples	Parts grade 1	Parts grade 2	Parts grade 3	Parts grade Below grade
		4-FOOT LENGTH					6-FOOT LENGTH				
Yellow-poplar	1	21	47	34	14	5	10	73	21	4	2
	2	13	40	28	26	6	10	18	36	32	14
	3	14	12	34	44	10	10	9	10	44	37
	Below grade	10	16	21	11	52	10	12	13	2	73
Maple	1	25	67	14	6	13	10	63	27	10	0
	2	10	46	21	25	8	10	19	33	23	25
	3	10	8	20	36	36	10	8	21	36	35
	Below grade	10	16	14	11	59	10	2	2	32	64
Oak	1	21	54	21	8	17	10	64	24	0	12
	2	15	38	10	32	20	10	36	14	36	14
	3	16	16	9	26	49	10	2	14	40	44
	Below grade	10	6	7	7	80	10	7	7	22	64
Total	1	67	56	23	9	12	30	67	24	4	5
	2	38	41	19	28	12	30	24	28	30	18
	3	40	13	21	35	31	30	7	15	40	38
	Below grade	30	13	14	10	63	30	7	8	17	68

Graded pallet part yields by Present cant grades were:

Cant grade Present	Part grade yield (NWPCA)			
	1	2	3	Below grade
	percent			
1	48	27	14	11
2	29	18	24	29
3	18	26	18	38
Below grade	3	3	14	80

Differences in parts yield between species and cant length could not be distinguished statistically for cants classified by the Present rules.

A series of statistical procedures were applied to determine the classification system that was more closely related to the quality of pallet materials within the cant. Results indicate the interim system is more accurate by 33 percent. (The procedures and conclusions are given in the Appendix.)

Relative parts values generally applied in the pallet industry using Grade 3 value as the base are:

Below grade parts = 0.0
Grade 3 parts = 1.0
Grade 2 parts = 1.4
Grade 1 parts = 2.1

Where these relative values apply, the current value of each part by grade is determined by multiplying the current value of Grade 3 parts by the relative value of the appropriate part grade. For example: If Grade 3 parts are worth $125 per thousand board feet (M bf), the value for each part grade would be:

Part grade	*Relative value*	*Grade 3 value*	*Part value*
		dollars/M bf	
1	2.1	125	262.50
2	1.4	125	175
3	1.0	125	125
Below grade	0.0	125	0

These relative values were used to develop Table 2. To determine the value of parts from cants classified by the Interim system, the value of Grade 3 parts may be multiplied by the appropriate table value. For example, if the value of Grade 3 parts is $125 per M bf, the mean value of parts that could be sawed from 4-foot cants by class for all species combined is:

Interim cant class	*Table value*	*Grade 3 part value*	*Gross cant value*
		dollars/M bf	
1	1.584	125	198
2	1.383	125	172.88
3	0.880	125	110
Below grade	0.541	125	56.38

Where the relative parts values differ from the example, value tables can be developed by the formula:

$$\text{Cant Value Relative} = P_1 \cdot R_1 + P_2 \cdot R_2 + P_3 \cdot R_3 + P_4 \cdot R_4$$

For example:

If the parts price relatives are:

Grade 1 = 3.0
Grade 2 = 1.5
Grade 3 = 1.0
Below grade = 0.0,

The mean value relative for a No. 1 4-foot-long hardwood cant graded by the Interim system is:

$$(.47)(3.0) + (.27)(1.5) + (.15)(1.0) + (.11)(0) = 1.965$$

If the value of Grade 3 parts is $70/M bf, the mean gross value of parts from No. 1 4-foot hardwood cants is $70 × 1.965 or $137.55/M bf.

Table 2.—Interim classification system value relatives[a]

Interim class	Length (feet)	Actual means (weighted)							
		N[b]	Poplar	N	Maple	N	Oak	M	All
1	4	21	1.566	25	1.673	21	1.497	67	1.584
1	6	10	1.888	10	1.798	10	1.668	30	1.785
2	4	13	1.472	10	1.487	15	1.238	38	1.383
2	6	10	1.198	10	1.075	10	1.276	30	1.183
3	4	14	1.192	10	0.771	16	0.675	40	0.880
3	6	10	0.753	10	0.831	10	0.665	30	0.750
Below grade	4	10	0.730	10	0.592	10	0.301	30	0.541
Below grade	6	10	0.437	10	0.403	10	0.488	30	0.443
All	4	58	1.310	55	1.279	62	1.029	175	1.201
All	6	40	1.069	40	1.027	40	1.024	120	1.040

[a] Value relatives based on the relation: Class 1 parts = 2.1; Class 2 parts = 1.4; Class 3 parts = 1.0; Below grade parts = 0. For other value relationships, tabular values are calculated by the formula: $P_1 \cdot R_1 + P_2 \cdot R_2 + P_3 \cdot R_3 + P_4 \cdot R_4$
[b] N = Number of samples.

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Appendix

Cant Quality Classification

Since no published pallet cant grading system is available, we devised interim quality classes for use in the study. The following summarizes minimum specifications for each of four classes of cants:

Class 1

Sawed knots. Maximum dimension 1/3 face width. Multiple knot dimensions additive if within 3 inches of each other. None over 1/2 inch in edges or end 3 inches.

Unsound knots and holes. Unsound or loose knots or holes may not exceed 1/6 width of cant face.

Cross grain. Not greater than 1:10 except in vicinity of knots and burls.

Split, shake, checks. Singly or in combination not to exceed 1/3 cant length, except 3 inches or less long are ignored.

Wane. May not exceed 1/2-inch width on any edge of the cant.

Manufacture. 75 percent of pieces must be at least of specified dimensions, and may not exceed 1/4-inch thickness in excess of specified dimension; 25 percent may be within − 1/8 and + 1/4 inch of specified dimension.

Class 2

Sound knots. Maximum dimension 1/2 face width. Dimensions of clustered knots additive if within 3 inches of each other. None over 1 inch in edges or end 3 inches.

Unsound knots or holes. Unsound knots, loose knots, or holes may not exceed 1/4 width of cant face.

Cross grain. Not greater than 1:6 except in vicinity of knots and burls.

Splits, checks, shake. Singly or in combination, may not exceed 1/2 of cant length. Those less than 3 inches long are ignored.

Wane. May not exceed ⅝-inch width on any edge of the cant.

Manufacture. 66-2/3 percent of pieces must be at least of specified dimensions, and may not exceed 1/4-inch thickness in excess of specified dimension; 33-1/3 percent of pieces may be within − 1/8 inch and + 1/4 inch of specified dimension.

Class 3

Sound knots. No size limitation.

Unsound knots and holes. Unsound knots, loose knots, or holes may not exceed 1/2 width of cant face.

Cross grain. No limitation.

Splits, checks, shake. Singly or in combination, may not exceed 3/4 of cant length; those less than 3 inches long are ignored.

Wane. May not exceed 3/4-inch width of any edge of the cant.

Manufacture. All pieces must be within − 1/8 inch and + 1/4 inch of specified dimension.

Below grade. Cants that do not meet Class 3 specification.

Interim Grading System

The interim pallet cant grading system has not been adopted by industry. Most cants currently are purchased by some variation of the following rules (Present).

Class 1

Sound end and faces 1/4-inch wane on not more than two faces.

Class 2

Sound-Square-Edge grade as defined in NHLA Rule Book, 1978, p. 74.

Class 3

Common Timbers & Industrial Blocking Grade as defined in NHLA Rule Book, 1978, p. 75.

Statistical Analysis for Value Relations

The mean value relative ($\overline{VR}$) for the entire sample was: $\overline{VR} = 1.135$ with standard deviation (S) S = 0.6112. If the cants are now classified by Present rules, the following results are obtained:

Present class	No. cants	$\overline{VR}$	S
1	70	1.499	0.476
2	195	1.091	0.586
3	16	0.884	0.474
4 (Below grade)	14	0.214	0.368

An analysis of variance (ANOVA) with a Duncan's Multiple Range Test yields the following results:

1. No difference between Grades 2 and 3

2. Pooled standard deviation = 0.548

3. $R^2 = 0.205$

Classifying the same cants with the proposed system (interim) yields the following results:

Interim class	No. cants	$\overline{VR}$	S
1	97	1.646	0.399
2	68	1.295	0.433
3	70	0.824	0.399
4 (Below grade)	60	0.492	0.457

Similarly, an ANOVA with a Duncan's Multiple Range Test performed yields these results:

1. All classes different

2. Pooled standard deviation = 0.419

3. $R^2 = 0.535$

A comparison of the two analyses reveals the following pertinent points:

1. The Interim system produces a more uniform distribution of the cants into classes. Note that with the Present system, 66 percent of all cants were grade 2 cants, only 5 percent were Grade 3, and another 5 percent were Grade 4.

2. The differences between adjacent mean value relatives for both systems are:

Classes	*Difference (Present)*	*Difference (Interim)*
1, 2	0.408	0.351
2, 3	0.207*	0.471
3, 4	0.670	0.332

*Not significant.

Note the more uniform spacing between the Interim system means.

3. The standard deviations for the Interim system are very consistent among classes. This is not true for the Present system. These are more variable with the largest standard deviation occurring in the Grade 2 cant class—the one that contains 66 percent of all cants. In fact, the standard deviation for this class (0.586) is nearly the same as the standard deviation with no grouping at all (0.6112).

The smallest standard deviation (0.368 in Grade 4) occurs in a class that contains only 5 percent of all cants.

Thus, the proposed system produces four distinct classes versus only three for the Present system. Further, the standard deviation is 23.5 percent smaller than that yielded by the Present system. This means that in using the proposed system (Interim) we can more accurately predict the value of the material within a group of cants and within significantly narrower limits.

Also noteworthy is that the Interim system of classification can explain 33 percent more of the variation among the value relatives than the Present system, i.e., 0.535 − 0.205 = 0.33 or 33 percent.

Craft, E. Paul; Whitenack, Kenneth R., Jr. A classification system for predicting pallet part quality from hardwood cants. Broomall, PA: Northeast. For. Exp. Stn.; 1982; USDA For. Serv. Res. Pap. NE-515. 7 p.

A system for classifying cants for pallet part production was developed that more accurately predicts the pallet parts grade mix that can be sawed from cants than the structural timber grades that are now used. A formula is given to determine value relatives for each cant class.

ODC: 739:834.9

Keywords: Pallet cant classes; value relatives

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- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
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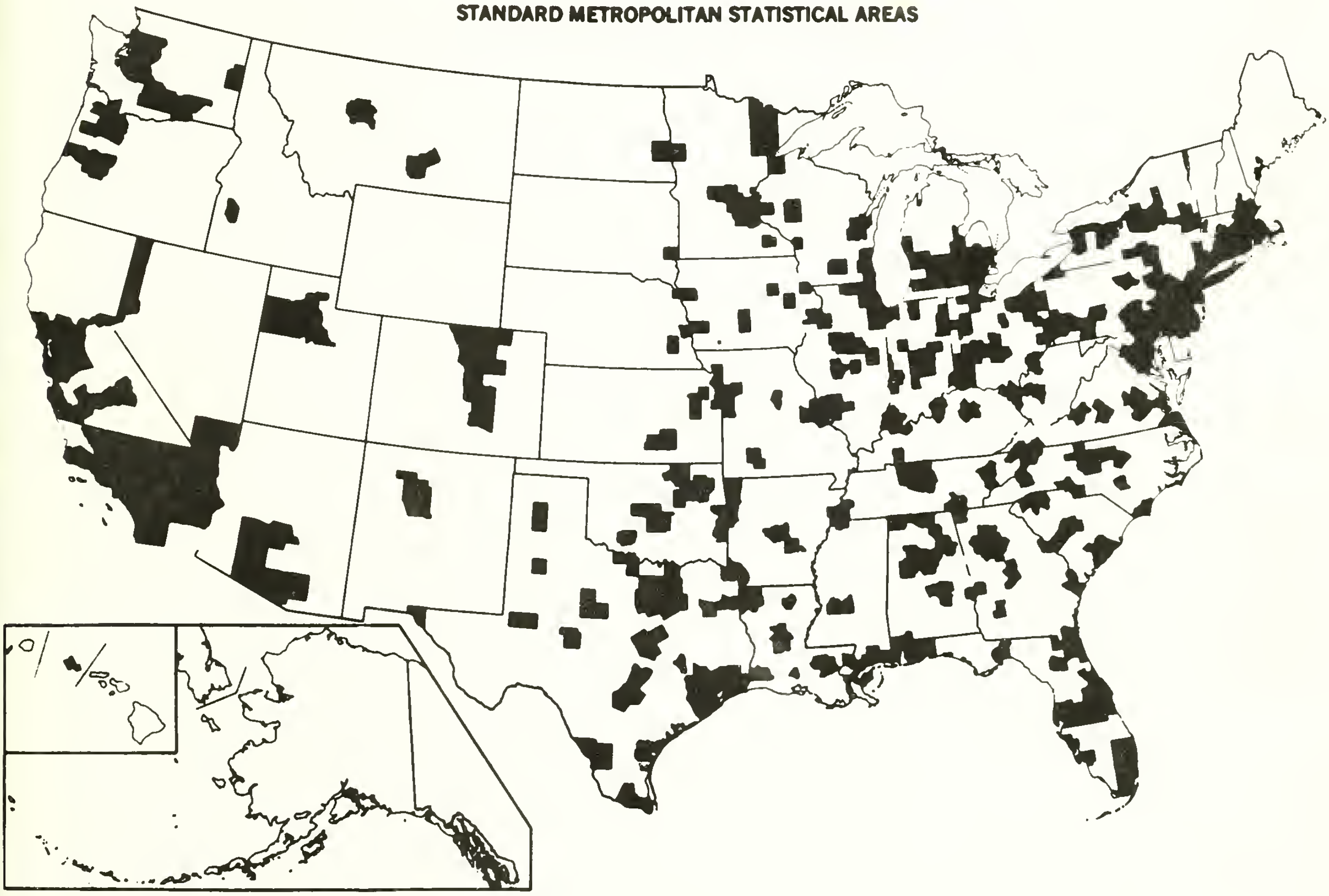
Classification
of American Metropolitan Areas by Ecoregion and Potential Natural Vegetation

Ralph A. Sanders
Rowan A. Rowntree

STANDARD METROPOLITAN STATISTICAL AREAS



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Abstract

This publication classifies 279 American metropolitan areas by ecoregion and potential natural vegetation. The classification forms a baseline of expected vegetation structure and composition that can assist scientists and policy makers in making urban forestry generalizations about classes of cities.

Contents

Introduction

Urban forestry researchers and planners ask: How similar or different are the urban forests of American cities? Specifically, for example, to what degree does the vegetation pattern of Richmond, Virginia resemble that of Wheeling, West Virginia, or Peoria, Illinois? How dissimilar are Phoenix and Spokane? If we were to complete an intensive vegetation survey of Omaha, could we extrapolate results to a class of similar cities?

Every city is a unique entity that shares some of its characteristics with others, and is able to be examined for its unique properties or for its general character. The similarity of cities has led to the idea of developing classifications.[1] Many early attempts at classification focused in the functional or economic character of cities and gave rise to single-level groups such as industrial cities, retailing cities, government cities, transportation cities, and so on. Later classification attempts were based on the morphology of the built environment (especially spatial arrangements), population growth histories, and positions with a hierarchy of city sizes. Recently an attempt was made to reflect the character of the population in urban typologies, and one classification for a limited set of American cities reflecting the physical environment was written.[2]

Similarly, a taxonomy of cities based on the composition and distribution of urban vegetation is desired. The classification would suggest: what the normal, average, or usual conditions are, how great the contrasts within and between cities are, and what regional or other patterns of similarity and dissimilarity exist. This information implies what may be true in one city from what is known by observation in another. It also would suggest how widespread one class of vegetation problems is and inform local policy makers which cities might have useful information. In general, this classification for urban forestry provides a basis for reliable inferences where knowledge is limited or unavailable, and lays a foundation for establishing scientific generalities and public policy guidelines with an economy of effort.

Generally, the composition and distribution of urban vegetation are determined by three broad categories of influence: the natural environment; the growing space available; and the human influences on selection, planting, removal, and maintenance. Cities may be classified by the pattern of aboveground growing space made available by the physical morphology of artificial surfaces. Also, cities may be classified by the aggregate impact of human choices and actions. We selected the simplest factor: natural environment, which is a logical point of departure for generalizing about urban vegetation in different parts of the United States, because of recent work in mapping ecological regions.

Our classification system is based on the assumption that attributes of the natural environment—climate, soils, gemorphology, and the regional vegetation itself—offer constraints and opportunities for molding the vegetation within the urban area. Of course, this premise acknowledges the importance of the other two factors, the distribution of available growing space and human influences that work in conjunction with the natural environment.

Reliable inventories of urban vegetation in the United States, obtained either from on-ground surveys or from remote sensing imagery, do not exist. Existing inventories are confined to specific subsets of urban vegetation, usually street tree populations and urban public parks. These inventories are few and vary in information content (Sacksteder and Gerhold 1979). A systematic survey of urban vegetation characteristics for a large set of American cities, therefore, seems a distant hope, particularly because it is difficult to determine detailed vegetation characteristics from remote sensing. Satellite technology (using increased spatial resolution of the sensor apparatus and computer-aided interpretation of radiance values associated with vegetation characteristics) may offer long term promise because of its breadth and continuity of coverage and the alternative high cost of obtaining on-ground surveys or reliable manual interpretations of variable quality, low-altitude photography.

An alternative is to classify cities according to characteristics of potential vegetation. We suggest that knowledge of the regional natural environment in which the city is located provides a basis for predicting certain attributes of urban vegetation—all tree, shrub, and herbaceous vegetation in the urban area. Cities in hot, arid regions will tend to have vegetation reflecting those facts, and the vegetation of these cities usually would differ substantially from that in cool, moist regions. We believe that much urban vegetation, especially in less developed and exurban portions, tends to resemble the vegetation, at least in general terms, of the surrounding ecoregion. Whether this is true ultimately depends on the unique combination of natural and human-urban histories that have produced the current urban vegetation configuration. When such histories are available, we will know how and why the extant vegetation pattern differs from the expected regional "baseline" (of

[1] The most complete summary of urban classification systems is in Berry and Horton (1970), Chapter 5 (p. 106–149) and Chapter 6 (p. 150–168).

[2] Berry and coworkers (1974) applied Q-mode factor analysis to a matrix containing measures of air, water, solid waste, pesticide, radiation, and noise pollution for 76 metropolitan areas to develop a taxonomy that describes how city characteristics and pollution covary for these cities.

potential natural vegetation). Two categories of influence that explain variations from the regional baseline are the unique distribution of growing spaces in the city, and the set of human preferences for species, ages, and conditions of plants.

There are at least three reasons why urban vegetation may resemble the surrounding regional vegetation complex. First, every city contains sizable portions of residual or relict vegetation, particularly in the newer suburban fringes of the urbanized area. This vegetation tends to resemble that in the non-urbanized portions of the larger urban region, having fallen into the urban category during recent stages of urban growth. Second, residual urban vegetation and that at the urban periphery act as seed sources for natural or seminatural propagation processes. Third, the potentials for and limits on vegetation types and densities as defined by the regimes of temperatures, precipitation, and soil types probably do not differ appreciably from urban to rural locations within broad regional limits, except perhaps where intensive urban development at the city center and the effects of local topography create distinctive sites. Thus, we need a measure of the regional natural environment for plant growth and development that will serve as a baseline for predicting what the urban vegetation configuration might be in the absence of direct human interference.

This natural region approach to urban classification lacks the vastly important anthropogenic or cultural component or urban vegetation. The myriad decisions to breed, plant, maintain, and remove vegetation by home and business owners and by representatives of both private and public institutions collectively establish a controlling environment for plants, the particular results of which have never been determined. A central question of urban forest science today is in what ways and to what degree, do anthropogenic influences on urban vegetation determine its final configuration. We conclude, however, that a classification of urban places according to the natural properties of the regions of which they are a part provides a useful guide to the similarities and differences in urban vegetation.

Method of Classification

For this classification, the population of American cities is taken as the complete set of Standard Metropolitan Statistical Areas (SMSA's) as of 1979. According to U.S. Bureau of the Census definitions, there are 279 SMSA's in the 50 states covering about 20 percent of the nation's land area. As a set, these SMSA's represent all urban places which contain at least one central city (a political entity) with a population of at least 50,000 and the counties in which the surrounding economically integrated populations are contained. The county basis for defining SMSA's, therefore, incorporates into the urban definition substantial tracts of what might be thought of as nonurban land, land which in the eyes of some researchers, however, can be regarded largely as "preurban," assuming a continuation of metropolitan decentralization trends. The 279 SMSA's examined in this study represent all the large urban areas in the United States.

To delimit the natural environment of the urban places to project likely characteristics of urban vegetation or sizable portions of it, two variables are used: (1) the "ecoregion" in which the city is located, and (2) the Potential Natural Vegetation (PNV) of that location. Each of these has been succinctly described and mapped (Bailey 1980, USDA Forest Service 1978).

The ecoregions devised by Bailey reflect the distinctive flora, fauna, climate, landform, soil, vegetation, and ecological climax of a continuous geographical area. These regions differ from surrounding regions in one or more important ecological associations or in the proportions of the area covered by distinctive associations. The ecoregion system is organized into a four-tiered hierarchy, each level representing a subdivision of the area encompassed by the preceding hierarchical level. These levels, from upper to lower, are domain, division, province, and section. For the purpose of this classification, urban places were located at the division level, which differentiates regions primarily according to vegetation and climate, but allows the classification to remain relatively simple. The metropolitan areas of the United States are located in 11 of the 12 ecoregion divisions. The ecoregion division reflects the general availability of heat and moisture, both determinants of the limitations on and potentials for regional associations of vegetation, and the PNV is simply a more specific variable describing the natural environment.

The PNV of an area is the vegetation that would exist today if man were (now) removed from the scene and if the plant succession after his removal were telescoped into a single moment (Küchler 1964). It reflects both the life-forms (physiognomy and structure) and the taxa (dominant genera for the regions of PNV). PNV is contrasted with actual or real vegetation, which is normally expressed or mapped as a statistic depiction of the regional vegetation at a point in time, independent of any impetus or direction of change. We chose PNV over existing vegetation for this classification because of the rapid change in land use in urban areas, particularly in inner city areas where population densities are falling and open spaces emerging, in suburban areas where land development processes are most active, and in exurban areas where the economic bases of farm and forest practices are increasingly challenged by the prospect of continuing metropolitan decentralization. The existing vegetation in these places (even if this were now classified) probably would be a poor predictor of developing urban vegetation configurations. PNV suggests what kinds of vegetation are possible in these areas.

Using Bailey's recent map, we recorded the ecoregion division and PNV for each of the 279 SMSA's. These were determined by finding the exact locations of SMSA's on the Bailey map, and determining the correct classifications at the visual center of the SMSA. Where natural boundaries of ecoregions or PNV appeared to bisect the metropolitan area, only that zone which was judged to cover the greatest portion of the SMSA was recorded. This preserved simplicity in the classification system. The literal interpretation of natural boundaries on maps can be a misleading exercise, because most of these represent gradual transitions of natural characteristics from one region to another, and many boundaries merely reflect only the change in proportions of several of the dominant natural characteristics. This means that any attempt of a natural urban classification for any large set of metropolitan areeas is imprecise, and needs substantial improvements in the quality of natural environmental data derived for local sources.

Results

The lack of high-quality local data and the forced reliance on generalized natural maps prohibit highly literal interpretations of the classification outlined here. The classification merely suggests the likely similarity and dissimilarity of the wild component of urban vegetation between metropolitan areas. In this sense, the classification refers less to the specific character of vegetation in an urban place than to the likelihood of resemblance with like places.

A summary of the natural-urban classification resulting from this process is given in Table 1. More than half of the American metropolitan areas are in the Hot Continental and Subtropical ecoregion divisions. From the perspective of vegetation, roughly two-thirds of the SMSA's are located within the Eastern Broadleaf and the Eastern Needleleaf and Broadleaf Forests (PNV). This implies that a large number of these urban places share similar vegetation characteristics, and identification of and solutions to both scientific and public policy problems in any one place may be applied in others. In contrast, seven metropolitan areas occupy unique positions in this classification system, and many others represent a typical or special cases in the classification, sharing their natural characteristics with only one or two urban places. Scientific or public policy solutions learned in these cities may not be applied easily to other cities.

The detailed results of the classification are given in three cross-indexed lists. Appendix II lists the SMSA's alphabetically by the name of the city (or principal city) in the metropolitan area, so individual cities may be located easily in the classification. In Appendix II, the ecoregion division and PNV are given for each place. Appendix III classifies SMSA's by Ecoregion Division (alphabetically by states) and theses are cross-referenced for PNV. Appendix IV lists cities by zones of PNV, organizing these broadly into life-form zones. By listing metropolitan areas in each of these ways, the classification system provides a convenient description of urban natural classes, the internal composition of any class, and the particular classification of any one urban place.

Table 1.—Summary classification of SMSA's by ecoregion and by potential natural vegetation

Potential Natural Vegetation by Ecosystem Regions	Ecoregion division											Total
	Sub-arctic	Warm Contin-ental	Hot Contin-ental	Sub-trop-ical	Marine	Prairie	Medi-terran-ean	Steppe	Desert	Savanna	Rain-forest	
West Needle leaf forest	—	1	—	—	3	—	—	—	—	—	—	4(1.4)[a]
West Needle leaf and Broadleaf forest	—	—	—	—	3	—	3	—	—	—	—	6(2.2)
West Shrub	—	—	—	—	—	1	3	2	3	—	—	9(3.2)
West Grass-land	—	—	—	—	2	—	8	1	—	—	—	11(3.9)
West Shrub and Grass-land	—	—	—	—	—	2	—	4	1	—	—	7(2.5)
Central and East Grass-land	—	—	—	2	—	11	—	10	—	—	—	23(8.2)
Central and East Grass-land and forest	—	—	8	—	—	14	—	—	—	—	—	22(7.9)
East Needle leaf forest	—	2	—	—	—	—	—	—	—	—	—	2(0.7)
East Broad-leaf forest	—	6	90	1	—	15	—	2	—	—	—	114(40.9)
East Needle leaf and Broadleaf	—	14	4	58	—	—	—	—	—	3	—	79(28.3)
Alaskan Types	1	—	—	—	—	—	—	—	—	—	—	1(0.4)
Hawaiian type	—	—	—	—	—	—	—	—	—	—	1	1(0.4)
Total	1 (0.4)	23 (8.2)	102 (36.6)	61 (21.9)	8 (2.9)	43 (15.4)	14 (5.0)	19 (6.8)	4 (1.4)	3 (1.0)	1 (0.4)	279(100.0)

[a] Number in parentheses is the percentage of total SMSA's in given category.

Appendix I

Code Numbers

Code numbers for ecoregion divisions and for potential natural vegetation used in subsequent appendixes.[3]

Code	*Ecoregion division*
1300	Subartic
2100	Warm Continental
2200	Hot Continental
2300	Subtropical
2400	Marine
2500	Prairie
2600	Mediterranean
3100	Steppe
3200	Desert
4100	Savanna
4200	Rainforest

Code	*Potential natural vegetation, by ecosystem regions*
1–21	Western Needleleaf Forest
22–23	Western Broadleaf Forest
24–28	Western Needleleaf and Broadleaf Forest
29–39	Western Shrub
40–48	Western Grassland
49–55	Western Shrub and Grassland
56–71	Central and Eastern Grassland
72–83	Central and Eastern Grassland and Forest Combination
84–88	Eastern Needleleaf Forest
89–96	Eastern Broadleaf Forest
97–106	Eastern Needleleaf and Broadleaf Forest
111–120	Ecosystems of Alaska
121–127	Ecosystems of Hawaii

[3] Code numbers are listed and mapped by Bailey (1978)

Appendix II

Alphabetical list of SMSA's by ED and PNV.

SMSA	*ED*	*PNV*
Abilene, TX	2500	76
Akron, OH	2200	93
Albany, GA	2300	102
Albany-Schenectady-Troy, NY	2100	97
Albuquerque, NM	3100	47
Alexandria, LA	2300	101
Allentown-Bethlehem-Easton, PA	2200	95
Altoona, PA	2200	95
Amarillo, TX	3100	58
Anaheim-Santa Ana-Garden Grove, CA	2600	41
Anchorage, AK	1300	113
Anderson, IN	2200	93
Ann Arbor, MI	2200	91
Anniston, Al	2300	101
Appleton-Oshkosh, WI	2200	90
Asheville, NC	2200	95
Atlanta, GA	2300	101
Atlantic City, NJ	2300	65
Augusta, GA-SC	2300	101
Austin, TX	2500	68
Bakersfield, CA	2600	34
Baltimore, MD	2300	101
Baton Rouge, LA	2300	91
Battle Creek, MI	2200	91
Bay City, MI	2100	92
Beaumont-Port Arthur-Orange, TX	2300	69
Billings, MT	3100	89
Biloxi-Gulfport, MS	2300	102
Binghamton, NY-PA	2100	97
Birmingham, AL	2300	101
Bismarck, ND	3100	89
Bloomington, IN	2200	93
Bloomington-Normal, IL	2500	73
Boise City, ID	3100	49
Boston, MA	2200	95
Bradenton, FL	2300	102
Bridgeport, CT	2200	95
Bristol, CT	2200	95
Brockton, MA	2100	97
Brownsville-Harlingen-San Benito, TX	2500	54
Bryan-College Station, TX	2500	91
Buffalo, NY	2200	93
Burlington, NC	2300	101
Canton, OH	2200	95
Cedar Rapids, IA	2500	91
Champaign-Urbana-Rantoul, IL	2300	101
Charleston, WV	2200	94
Charlotte-Gastonia, NC	2300	101
Chattanooga, TN-GA	2200	101
Chicago, IL	2500	73
Cincinnati, OH-KY-IN	2200	91
Clarksville-Hopkinsville, TN-KY	2200	91
Cleveland, OH	2200	93
Colorado Springs, CO	3100	58
Columbia, MO	2200	91
Columbia, SC	2300	101
Columbus, GA-AL	2300	101
Columbus, OH	2200	93
Corpus Christi, TX	2500	69
Dallas-Fort Worth, TX	2500	68

Appendix II (Cont.)

SMSA	ED	PNV
Danbury, CT	2200	95
Davenport-Rock Island-Moline, IA-IL	2500	91
Dayton, OH	2200	91
Daytona Beach, FL	2300	102
Decatur, IL	2500	91
Denver-Boulder, CO	3100	58
Des Moines, IA	2500	91
Detroit, MI	2200	92
Dubuque, IA	2200	90
Duluth-Superior, MN-WI	2100	86
Eau Claire, WI	2200	72
Elkhart, IN	2200	91
El Paso, TX	3200	52
Elmira, NY	2100	95
Erie, PA	2200	93
Eugene-Springfield, OR	2400	24
Evansville, IN-KY	2200	103
Fall River, MA-RI	2200	95
Fargo-Moorhead, ND-MN	2500	89
Fayetteville, NC	2300	101
Fayetteville-Springdale, AR	2200	91
Fitchburg-Leominster, MA	2100	97
Flint, MI	2200	91
Florence, AL	2200	91
Fort Collins, CO	3100	58
Fort Lauderdale-Hollywood, FL	4100	102
Fort Myers, FL	2300	102
Fort Smith, AR-OK	2200	103
Fort Wayne, IN	2200	91
Fresno, CA	2600	41
Gadsden, AL	2300	101
Gainesville, FL	2300	102
Galveston-Texas City, TX	2500	70
Gary-Hammond-East Chicago, IN	2200	91
Grand Forks, ND-MN	2500	89
Grand Rapids, MI	2200	93
Great Falls, MT	3100	56
Greeley, CO	3100	58
Green Bay, WI	2100	97
Greensboro-Winston-Salem-High Point, NC	2300	101
Greenville-Spartansburg, SC	2300	101
Hamilton-Middletown, OH	2200	93
Harrisburg, PA	2200	95
Hartford, CT	2200	95
Honolulu, HI	4200	121
Houston, TX	2500	69
Huntington-Ashland, WV-KY-OH	2200	94
Huntsville, AL	2200	74
Indianapolis, IN	2200	93
Jackson, MI	2200	92
Jackson, MS	2300	101
Jacksonville, FL	2300	102
Jersey City, NJ	2200	95
Johnson City-Kingsport-Bristol, TN-VA	2200	95
Johnstown, PA	2200	95
Kalamazoo-Portage, MI	2200	91
Kankakee, IL	2500	73
Kansas City, MO-KS	2500	91
Kenosha, WI	2200	72
Killeen-Temple, TX	2500	68
Knoxville, TN	2200	95
Kokomo, IN	2200	93
La Crosse, WI	2200	90
Lafayette, LA	2300	103
Lafayette-West Lafayette, IN	2200	91
Lake Charles, LA	2300	102
Lakeland-Winter Haven, FL	2300	102
Lancaster, PA	2200	95
Lansing-East Lansing, MI	2200	93
Laredo, TX	2500	38
Las Vegas, NV	3200	35
Lawrence, KS	2500	73
Lawrence-Haverhill, MA-NH	2200	95
Lawton, OK	2500	62
Lewiston-Auburn, ME	2100	97
Lexington-Fayette, KY	2200	91
Lima, OH	2200	93
Lincoln, NE	2500	89
Little Rock-North Little Rock, AR	2300	101
Long Branch-Asbury Park, NJ	2200	95
Longview, TX	2300	101
Lorain-Elyria, OH	2200	92
Los Angeles-Long Beach, CA	2600	41
Louisville, KY-IN	2200	91
Lowell, MA-NH	2100	97
Lubbock, TX	3100	58
Lynchburg, VA	2300	101
Macon, GA	2300	101
Madison, WI	2200	72
Manchester, NH	2100	97

Appendix II (Cont.)

SMSA	*ED*	*PNV*
Mansfield, OH	2200	93
McAllen-Pharr-Edinburg, TX	2500	54
Melbourne-Titusville-Cocoa, Fl	2300	102
Memphis, TN-AR-MS	2300	103
Meriden, CT	2200	95
Miami, FL	4100	106
Midland, TX	3100	58
Milwaukee, WI	2200	90
Minneapolis-St. Paul, MN-WI	2200	72
Mobile, AL	2300	102
Modesto, CA	2600	42
Monroe, LA	2300	103
Montgomery, AL	2300	103
Muncie, IN	2200	93
Muskegon-North Shores-Muskegon Heights, MI	2100	86
Nashua, NH	2100	97
Nashville-Davidson, TN	2200	91
Nassau-Suffolk, NY	2200	100
New Bedford, MA	2200	95
New Britain, CT	2200	95
New Brunswick-Perth Amboy-Sayreville, NJ	2200	95
New Haven-West Haven, CT	2200	95
New London-Norwich, CT	2200	95
New Orleans, LA	2300	103
New York, NY-NJ	2200	95
Newark, NJ	2200	95
Newport News-Hampton, VA	2300	101
Norfolk-Virginia Beach-Portsmouth, VA-NC	2300	101
Norwalk, CT	2200	95
Odessa, TX	3100	58
Oklahoma City, OK	2500	62
Omaha, NE-IA	2500	91
Orlando, FL	2300	102
Owensboro, KY	2200	91
Oxnard-Simi Valley-Ventura, CA	2600	26
Panama City, FL	2300	102
Parkersburg-Marietta, WV-OH	2200	95
Pascagoula-Moss Point, MS	2300	102
Paterson-Clifton-Passaic, NJ	2200	95
Pensacola, FL	2300	102
Peoria, IL	2500	91
Petersburg-Colonial Heights-Hopewell, VA	2300	101
Philadelphia, PA-NJ	2200	95
Phoenix, AZ	3200	36
Pine Bluff, AR	2300	101

SMSA	*ED*	*PNV*
Pittsburgh, PA	2200	95
Pittsfield, MA	2100	97
Portland, ME	2100	97
Portland, OR-WA	2400	2
Poughkeepsie, NY	2100	95
Providence-Warwick-Pawtucket, RI	2200	95
Provo-Orem, UT	3100	31
Pueblo, CO	3100	58
Racine, WI	2200	90
Raleigh-Durham, NC	2300	101
Reading, PA	2200	95
Reno, NV	3100	49
Richland-Kennewick, WA	3100	49
Richmond, VA	2300	101
Riverside-San Bernardino-Ontario, CA	2600	30
Roanoke, VA	2300	101
Rochester, MN	2200	90
Rochester, NY	2100	97
Rockford, IL	2500	73
Sacramento, CA	2600	42
Saginaw, MI	2100	92
St. Cloud, MN	2200	72
St. Joseph, MO	2500	73
St. Louis, MO-IL	2200	91
Salem, OR	2400	42
Salinas-Seaside-Monterey, CA	2600	41
Salt Lake City-Ogden, UT	3100	32
San Angelo, TX	2500	76
San Antonio, TX	2500	78
San Diego, CA	2600	30
San Francisco-Oakland, CA	2400	40
San Jose, CA	2600	40
Santa Barbara-Santa Maria-Lompoc, CA	2600	26
Santa Cruz, CA	2600	26
Santa Rosa, CA	2400	25
Sarasota, FL	2300	102
Savannah, GA	2300	102
Scranton-Wilkes-Barre-Hazleton, PA	2100	95
Seattle-Everett, WA	2400	2
Sherman-Denison, TX	2500	75
Shreveport, LA	2300	103
Sioux City, IA-NE	2500	66
Sioux Falls, SD	2500	66
South Bend, IN	2200	91
Spokane, WA	2100	11

Appendix II (Cont.)

SMSA	*ED*	*PNV*
Springfield, IL	2500	91
Springfield-Chicopee-Holyoke, MA-CT	2200	95
Springfield, MO	2200	73
Springfield, OH	2200	73
Stamford, CT	2200	95
Steubenville-Weirton, OH-WV	2200	95
Stockton, CA	2600	42
Syracuse, NY	2100	97
Tacoma, WA	2400	2
Tallahassee, FL	2300	102
Tampa-St. Petersburg, FL	2300	102
Terre Haute, IN	2500	91
Texarkana, TX-Texarkana, AR	2300	101
Toledo, OH-MI	2200	92
Topeka, KS	2500	73
Trenton, NJ	2200	95
Tuscon, AZ	3200	36
Tulsa, OK	2500	75
Tuscaloosa, AL	2300	101
Tyler, TX	2300	101
Utica-Rome, NY	2100	93
Vallejo-Fairfield-Napa, CA	2400	40
Vineland-Millville-Bridgeton, NJ	2300	100
Waco, TX	2500	68
Washington, DC-MD-VA	2300	101
Waterbury, CT	2200	95
Waterloo-Cedar Falls, IA	2500	91
West Palm Beach-Boca Raton, FL	4100	102
Wheeling, WV-OH	2200	95
Wichita, KS	2500	89
Wichita Falls, TX	2500	76
Williamsport, PA	2200	95
Wilmington, DE-NJ-MD	2200	95
Wilmington, NC	2300	102
Worcester, MA	2100	97
Yakima, WA	3100	49
York, PA	2200	95
Youngstown-Warren, OH	2200	93

Appendix III

SMSA Classification by ED[4]

		PNV
1300	*SUBARCTIC DIVISION*	
	Alaska	
	Anchorage	113
2100	*WARM CONTINENTAL DIVISION*	
	Maine	
	Lewiston-Auburn	97
	Portland	97
	Massachusetts	
	Brockton	97
	Fitchburg-Leominster	97
	Lowell	97
	Worcester	97
	Michigan	
	Bay City	92
	Muskegon-North Shores-Muskegon Heights	86
	Saginaw	92
	Minnesota	
	Duluth-Superior	86
	New Hampshire	
	Manchester	97
	Nashua	97
	New York	
	Albany-Schenectady-Troy	97
	Binghamton	97
	Elmira	95
	Poughkeepsie	95
	Rochester	97
	Syracuse	97
	Utica-Rome	97
	Pennsylvania	
	Scranton-Wilkes-Barre-Hazelton	95
	Washington	
	Spokane	11
	Wisconsin	
	Green Bay	97

[4] The list of SMSA's within ecoregion divisions is arranged alphabetically by state. Note that for SMSA's with compound names the state of the first-named urban place is given and the state of the second or third-named urban place is not given.

Appendix III (Cont.)

2200 HOT CONTINENTAL DIVISION	PNV
Alabama	
Florence	91
Huntsville	74
Arkansas	
Fayetteville-Springdale	91
Fort Smith	103
Connecticut	
Bridgeport	95
Bristol	95
Danbury	95
Hartford	95
Meriden	95
New Britain	95
New Haven-West Haven	95
New London-Norwich	95
Norwalk	95
Stamford	95
Waterbury	95
Delaware	
Wilmington	95
Indiana	
Anderson	93
Bloomington	93
Elkhart	91
Evansville	103
Fort Wayne	91
Gary-Hammond-East Chicago	91
Indianapolis	93
Kokomo	93
Lafayette-West Lafayette	91
Muncie	93
South Bend	91
Iowa	
Dubuque	90
Kentucky	
Lexington-Fayette	91
Louisville	91
Owensboro	91
Massachusetts	
Boston	95
Fall River	95
Lawrence-Haverhill	95
New Bedford	95
Springfield-Chicopee-Holyoke	95
Michigan	
Ann Arbor	91
Battle Creek	91
Detroit	92
Flint	91
Grand Rapids	93
Jackson	92
Kalamazoo-Portage	91
Lansing-East Lansing	93
Minnesota	
Minneapolis-St. Paul	72
Rochester	90
St. Cloud	72

	PNV
Missouri	
Columbia	91
St. Louis	91
Springfield	73
New Jersey	
Jersey City	95
Long Branch-Asbury Park	95
New Brunswick-Perth Amboy-Sayreville	95
Newark	95
Paterson-Clifton-Passaic	95
Trenton	95
New York	
Buffalo	93
Nassau-Suffolk	100
New York	95
North Carolina	
Asheville	95
Ohio	
Akron	93
Canton	95
Cincinnati	91
Cleveland	93
Columbus	93
Dayton	91
Hamilton-Middletown	93
Lima	93
Lorain-Elyria	92
Mansfield	93
Springfield	73
Steubenville-Weirton	95
Toledo	92
Youngstown-Warren	93
Pennsylvania	
Allentown-Bethlehem-Easton	95
Altoona	95
Erie	93
Harrisburg	95
Johnstown	95
Lancaster	95
Philadelphia	95
Pittsburgh	95
Reading	95
Williamsport	95
York	95
Rhode Island	
Providence-Warwick-Pawtucket	95
Tennessee	
Chattanooga	101
Clarksville-Hopkinsville	91
Johnson City-Kingsport-Bristol	95
Knoxville	95
Nashville-Davidson	91
West Virginia	
Charleston	94
Huntington-Ashland	94
Parkersburg-Marietta	95
Wheeling	95

Appendix III (Cont.)

		PNV
	Wisconsin	
	Appleton-Oshkosh	90
	Eau Claire	72
	Kenosha	72
	La Crosse	90
	Madison	72
	Milwaukee	90
	Racine	90
2300	*SUBTROPICAL DIVISION*	
	Alabama	
	Anniston	101
	Birmingham	101
	Gadsden	101
	Mobile	102
	Montgomery	103
	Tuscaloosa	101
	Arkansas	
	Little Rock-North Little Rock	101
	Pine Bluff	101
	District of Columbia	
	Washington	101
	Florida	
	Bradenton	102
	Daytona Beach	102
	Fort Myers	102
	Gainesville	102
	Jacksonville	102
	Lakeland-Winter Haven	102
	Melbourne-Titusville-Cocoa	102
	Orlando	102
	Panama City	102
	Pensacola	102
	Sarasota	102
	Tallahassee	102
	Tampa-St. Petersburg	102
	Georgia	
	Albany	102
	Atlanta	101
	Augusta	101
	Columbus	101
	Macon	101
	Savannah	102
	Louisiana	
	Alexandria	101
	Baton Rouge	91
	Lafayette	103
	Lake Charles	102
	Monroe	103
	New Orleans	103
	Shreveport	103
	Maryland	
	Baltimore	101
	Mississippi	
	Biloxi-Gulfport	102
	Jackson	101
	Pascagoula-Moss Point	102

		PNV
	New Jersey	
	Atlantic City	65
	Vineland-Millville-Bridgeton	100
	North Carolina	
	Burlington	101
	Charlotte-Gastonia	101
	Fayetteville	101
	Greensboro-Winston-Salem-High Point	101
	Raleigh-Durham	101
	Wilmington	102
	South Carolina	
	Charleston-North Charleston	101
	Columbia	101
	Greenville-Spartansburg	101
	Tennessee	
	Memphis	103
	Texas	
	Beaumont-Port Arthur-Orange	69
	Longview	101
	Texarkana	101
	Tyler	101
	Virginia	
	Lynchburg	101
	Newport News-Hampton	101
	Norfolk-Virginia Beach-Portsmouth	101
	Petersburg-Colonial Heights-Hopewell	101
	Richmond	101
	Roanoke	101
2400	*MARINE DIVISION*	
	California	
	San Francisco-Oakland	40
	Santa Rosa	25
	Vallejo-Fairfield-Napa	40
	Oregon	
	Eugene-Springfield	24
	Portland	2
	Salem	24
	Washington	
	Seattle-Everett	2
	Tacoma	2
2500	*PRAIRIE DIVISION*	
	Illinois	
	Bloomington-Normal	73
	Champaign-Urbana-Rantoul	73
	Chicago	73
	Decatur	91
	Kankakee	73
	Peoria	91
	Rockford	73
	Springfield	91
	Indiana	
	Terre Haute	91

Appendix III (Cont.)

		PNV
	Iowa	
	Cedar Rapids	91
	Davenport-Rock Island-Moline	91
	Des Moines	91
	Sioux City	66
	Waterloo-Cedar Falls	91
	Kansas	
	Lawrence	73
	Topeka	73
	Wichita	89
	Missouri	
	Kansas City	91
	St. Joseph	73
	Nebraska	
	Lincoln	89
	Omaha	91
	North Dakota	
	Fargo-Moorhead	89
	Grand Forks	89
	Oklahoma	
	Lawton	62
	Oklahoma City	62
	Tulsa	75
	South Dakota	
	Sioux Falls	66
	Texas	
	Abilene	76
	Austin	68
	Brownsville-Harlingen-San Benito	54
	Bryan-College Station	91
	Corpus Christi	69
	Dallas-Fort Worth	68
	Galveston-Texas City	70
	Houston	69
	Killeen-Temple	68
	Laredo	38
	McAllen-Pharr-Edinburg	54
	San Angelo	76
	San Antonio	78
	Sherman-Denison	75
	Waco	68
	Wichita Falls	76
2600	*MEDITERRANEAN DIVISION*	
	California	
	Anaheim-Santa Ana-Garden Grove	41
	Bakersfield	34
	Fresno	41
	Los Angeles-Long Beach	41
	Modesto	42
	Oxnard-Simi Valley-Ventura	26
	Riverside-San Bernardino-Ontario	30
	Sacramento	42
	Salinas-Seaside-Monterey	41
	San Diego	30
	San Jose	40
	Santa Barbara-Santa Maria-Lompoc	26
	Santa Cruz	26
	Stockton	42

3100	*STEPPE DIVISION*	PNV
	Colorado	
	Colorado Springs	58
	Denver-Boulder	58
	Fort Collins	58
	Greeley	58
	Pueblo	58
	Idaho	
	Boise City	49
	Montana	
	Billings	89
	Great Falls	56
	Nevada	
	Reno	49
	New Mexico	
	Albuquerque	47
	North Dakota	
	Bismarck	89
	Texas	
	Amarillo	58
	Lubbock	58
	Midland	58
	Odessa	58
	Utah	
	Provo-Orem	31
	Salt Lake City-Ogden	32
	Washington	
	Richland-Kennewick	49
	Yakima	49
3200	*DESERT DIVISION*	
	Arizona	
	Phoenix	36
	Tucson	36
	Nevada	
	Las Vegas	35
	Texas	
	El Paso	52
4100	*SAVANNA DIVISION*	
	Florida	
	Fort Lauderdale-Hollywood	102
	Miami	106
	West Palm Beach-Boca Raton	102
4200	*RAINFOREST DIVISION*	
	Hawaii	
	Honolulu	121

Appendix IV

SMSA Classification by Zones of PNV[5]

		ED
WESTERN NEEDLELEAF FOREST		
2	*Cedar—hemlock—Douglas-fir forest*	
	Portland, OR-WA	2400
	Seattle-Everett, WA	2400
	Tacoma, WA	2400
11	*Douglas-fir forest*	
	Spokane, WA	2100
WESTERN NEEDLELEAF AND BROADLEAF FOREST		
24	*Cedar—hemlock—Douglas-fir forest and Oregon oakwoods*	
	Eugene-Springfield, OR	2400
	Salem, OR	2400
25	*California mixed evergreen forest*	
	Santa Rosa, CA	2400
26	*California oakwoods*	
	Oxnard-Simi Valley-Ventura, CA	2600
	Santa Barbara-Santa Maria-Lompoc, CA	2600
	Santa Cruz, CA	2600
WESTERN SHRUB		
30	*Coastal sagebrush*	
	Riverside-San Bernardino-Ontario, CA	2600
	San Diego, CA	2600
31	*Mountain mahogany--oak scrub*	
	Provo-Orem, UT	3100
32	*Great Basin sagebrush*	
	Salt Lake City-Ogden, UT	3100
34	*Saltbrush-greasewood*	
	Bakersfield, CA	2600
35	*Creosote bush*	
	Las Vegas, NV	3200
36	*Creosote bush-bur sage*	
	Phoenix, AZ	3200
	Tucson, AZ	3200
38	*Ceniza shrub*	
	Laredo, TX	2500
WESTERN GRASSLAND		
40	*Fescue-oatgrass*	
	San Francisco-Oakland, CA	2400
	San Jose, CA	2600
	Vallejo-Fairfield-Napa, CA	2400
41	*California steppe*	
	Anaheim-Santa Ana-Garden Grove, CA	2600
	Fresno, CA	2600
	Los Angeles-Long Branch, CA	2600
	Salinas-Seaside-Monterey, CA	2600
42	*Tule marshes*	
	Modesto, CA	2600
	Sacramento, CA	2600
	Stockton, CA	2600
47	*Grama-galleta steppe*	
	Albuquerque, NM	3100
WESTERN SHRUB AND GRASSLAND		
49	*Sagebrush steppe*	
	Boise City, ID	3100
	Reno, NV	3100
	Richland-Kennewick, WA	3100
	Yakima, WA	3100
52	*Grama-tobosa shrubsteppe*	
	El Paso, TX	3200
54	*Mesquite-acacia-savanna*	
	Brownsville-Harlingen-San Benito, TX	2500
	McAllen-Pharr-Edinburg, TX	2500
CENTRAL AND EASTERN GRASSLANDS		
56	*Foothills prairie*	
	Great Falls, MT	3100
58	*Grama-buffalograss*	
	Amarillo, TX	3100
	Colorado Springs, CO	3100
	Denver-Boulder, CO	3100
	Fort Collins, CO	3100
	Greeley, CO	3100
	Lubbock, TX	3100
	Midland, TX	3100
	Odessa, TX	3100
	Pueblo, CO	3100
62	*Bluestem-grama prairie*	
	Lawton, OK	2500
	Oklahoma City, OK	2500
65	*Northern cordgrass prairie*	
	Atlantic City, NJ	2300
66	*Bluestem prairie*	
	Sioux City, IA-NE	2500
	Sioux City, SD	2500
68	*Blackland prairie*	
	Austin, TX	2500
	Dallas-Fort Worth, TX	2500
	Killeen-Temple, TX	2500
	Waco, TX	2500
69	*Bluestem-sacahuista prairie*	
	Beaumont-Port Arthur-Orange, TX	2300
	Corpus Christi, TX	2500
	Houston, TX	2500
70	*Southern cordgrass prairie*	
	Galveston-Texas City, TX	2500

[5] Based on Kuchler (1964). The numerical prefix to the PNV class corresponds to that given by Bailey (1978). The numerical suffix to the SMSA refers to the ecoregion division.

Appendix IV (Cont.)

		ED
CENTRAL AND EASTERN GRASSLAND AND FOREST COMBINATION		
72	*Oak savanna*	
	Eau Claire, WI	2200
	Kenosha, WI	2200
	Madison, WI	2200
	Minneapolis-St. Paul, MN-WI	2200
	St. Cloud, MN	2200
73	*Bluestem prairie and oak-hickory forest*	
	Bloomington-Normal, IL	2500
	Champaign-Urbana-Rantoul, IL	2500
	Chicago, IL	2500
	Kankakee, IL	2500
	Lawrence, KS	2500
	Rockford, IL	2500
	St. Joseph, MO	2500
	Springfield, OH	2200
	Springfield, MO	2200
	Topeka, KS	2500
74	*Cedar glades*	
	Huntsville, AL	2200
75	*Cross timbers*	
	Sherman-Denison, TX	2500
	Tulsa, OK	2500
76	*Mesquite-buffalo grass*	
	Abilene, TX	2500
	San Angelo, TX	2500
	Wichita Falls, TX	2500
78	*Mesquite-oak savanna*	
	San Antonio, TX	2500
EASTERN NEEDLELEAF FOREST		
86	*Great Lakes pine forest*	
	Muskegon-North Shores-Muskegon Heights, MI	2100
	Duluth-Superior, MN-WI	2100
EASTERN BROADLEAF FOREST		
89	*Northern floodplain forest*	
	Billings, MT	3100
	Bismarck, ND	3100
	Fargo-Moorhead, ND-MN	2500
	Grand Forks, ND-MN	2500
	Lincoln, NE	2500
	Wichita, KS	2500
90	*Maple—basswood forest*	
	Appleton-Oshkosh, WI	2200
	Dubuque, IA	2200
	La Crosse, WI	2200
	Milwaukee, WI	2200
	Racine, WI	2200
	Rochester, MN	2200
91	*Oak—hickory forest*	
	Ann Arbor, MI	2200
	Baton Rouge, LA	2300
	Battle Creek, MI	2200
	Bryan-College Station, TX	2500
	Cedar Rapids, IA	2500
	Cincinnati, OH-KY-IN	2200
	Clarksville-Hopkinsville, TN-KY	2200
	Columbia, MO	2200
	Davenport-Rock Island-Moline, IA-IL	2500
	Dayton, OH	2200
	Decatur, IL	2500
	Des Moines, IA	2500
	Elkhart, IN	2200
	Fayetteville-Springdale, AR	2200
	Flint, MI	2200
	Florence, AL	2200
	Fort Wayne, IN	2200
	Gary-Hammond-East Chicago, IN	2200
	Kalamazoo-Portage, MI	2200
	Kansas City, MO-KS	2500
	Lafayette-West Lafayette, IN	2200
	Lexington-Fayette, KY	2200
	Louisville, KY-IN	2200
	Nashville-Davidson, TN	2200
	Omaha, NE-IA	2500
	Owensboro, KY	2200
	Peoria, IL	2500
	St. Louis, MO-IL	2200
	South Bend, IN	2200
	Springfield, IL	2500
	Terre Haute, IN	2500
	Waterloo-Cedar Falls, IA	2500
92	*Elm-ash forest*	
	Bay City, MI	2100
	Detroit, MI	2200
	Jackson, MI	2200
	Lorain-Elyria, OH	2200
	Saginaw, MI	2100
	Toledo, OH-MI	2200
93	*Beech-maple forest*	
	Akron, OH	2200
	Anderson, IN	2200
	Bloomington, IN	2200
	Buffalo, NY	2200
	Cleveland, OH	2200
	Columbus, OH	2200
	Erie, PA	2200
	Grand Rapids, MI	2200
	Hamilton-Middletown, OH	2200
	Indianapolis, IN	2200
	Kokomo, IN	2200
	Lansing-East Lansing, MI	2200
	Lima, OH	2200
	Mansfield, OH	2200
	Muncie, IN	2200
	Utica-Rome, NY	2100
	Youngstown-Warren, OH	2200
94	*Mixed mesophytic forest*	
	Charleston, WV	2200
	Huntington-Ashland, WV-KY-OH	2200
95	*Appalachian oak forest*	
	Allentown-Bethlehem-Easton, PA	2200
	Altoona, PA	2200
	Asheville, NC	2200
	Boston, MA	2200
	Bridgeport, CT	2200

Appendix IV (Cont.)

		ED
	Bristol, CT	2200
	Canton, OH	2200
	Danbury, CT	2200
	Elmira, NY	2200
	Fall River, MA-RI	2200
	Harrisburg, PA	2200
	Hartford, CT	2200
	Jersey City, NJ	2200
	Johnson City-Kingsport-Bristol, TN-VA	2200
	Johnstown, PA	2200
	Knoxville, TN	2200
	Lancaster, PA	2200
	Lawrence-Haverhill, MA-NH	2200
	Long Branch-Asbury Park, NJ	2200
	Meriden, CT	2200
	New Bedford, MA	2200
	New Britain, CT	2200
	New Brunswick-Perth Amboy-Sayreville, NJ	2200
	New Haven-West Haven, CT	2200
	New London-Norwich, CT	2200
	New York, NY-NJ	2200
	Newark, NJ	2200
	Norwalk, CT	2200
	Parkersburg-Marietta, WV-OH	2200
	Paterson-Clifton-Passaic, NJ	2200
	Philadelphia, PA-NJ	2200
	Pittsburgh, PA	2200
	Poughkeepsie, NY	2100
	Providence-Warwick-Pawtucket, RI	2200
	Reading, PA	2200
	Scranton-Wilkes-Barre-Hazelton, PA	2100
	Springfield-Chicopee-Holyoke, MA-CT	2200
	Stamford, CT	2200
	Steubenville-Weirton, OH-WV	2200
	Trenton, NJ	2200
	Waterbury, CT	2200
	Wheeling, WV-OH	2200
	Williamsport, PA	2200
	Wilmington, DE-NJ-MD	2200
	York, PA	2200

EASTERN NEEDLELEAF AND BROADLEAF FOREST

		ED
97	*Northern hardwoods*	
	Albany-Schenectady-Troy, NY	2100
	Binghamton, NY-PA	2100
	Brockton, MA	2100
	Fitchburg-Leominster, MA	2100
	Green Bay, WI	2100
	Lewiston-Auburn, ME	2100
	Lowell, MA-NH	2100
	Manchester, NH	2100
	Nashua, NH	2100
	Pittsfield, MA	2100
	Portland, ME	2100
	Rochester, NY	2100
	Syracuse, NY	2100
	Worcester, MA	2100

		ED
100	*Northeastern oak—pine forest*	
	Nassau-Suffolk, NY	2200
	Vineland-Millville-Bridgeton, NJ	2300
101	*Oak—hickory—pine forest*	
	Alexandria, LA	2300
	Anniston, AL	2300
	Atlanta, GA	2300
	Augusta, GA-SC	2300
	Baltimore, MD	2300
	Birmingham, AL	2300
	Burlington, NC	2300
	Chattanooga, TN-GA	2200
	Charleston-North Carolina, SC	2300
	Charlotte-Gastonia, NC	2300
	Columbia, SC	2300
	Columbus, GA-AL	2300
	Fayetteville, NC	2300
	Gadsden, AL	2300
	Greensboro-Winston-Salem-High Point, NC	2300
	Greenville-Spartansburg, SC	2300
	Jackson, MS	2300
	Little Rock-North Little Rock, AR	2300
	Longview, TX	2300
	Lynchburg, VA	2300
	Macon, GA	2300
	Newport News-Hampton, VA	2300
	Norfolk-Virginia Beach-Portsmouth, VA-NC	2300
	Petersburg-Colonial Heights-Hopewell, VA	2300
	Pine Bluff, AR	2300
	Raleigh-Durham, NC	2300
	Richmond, VA	2300
	Roanoke, VA	2300
	Texarkana, TX-Texarkana, AR	2300
	Tuscaloosa, AL	2300
	Tyler, TX	2300
	Washington, DC-MD-VA	2300
102	*Southern mixed forest*	
	Albany, GA	2300
	Biloxi-Gulfport, MS	2300
	Bradenton, FL	2300
	Daytona Beach, FL	2300
	Fort Lauderdale-Hollywood, FL	4100
	Fort Myers, FL	2300
	Gainesville, FL	2300
	Jacksonville, FL	2300
	Lake Charles, LA	2300
	Lakeland-Winter Haven, FL	2300
	Melbourne-Titusville-Cocoa, FL	2300
	Mobile, AL	2300
	Orlando, FL	2300
	Panama City, FL	2300
	Pascagoula-Moss Point, MS	2300
	Pensacola, FL	2300
	Sarasota, FL	2300
	Savannah, GA	2300
	Tallahassee, FL	2300
	Tampa-St. Petersburg, FL	2300
	West Palm Beach-Boca Raton, FL	4100
	Wilmington, NC	2300

Appendix IV (Cont.)

		ED
103	*Southern floodplain forest*	
	Evansville, IN-KY	2200
	Fort Smith, AR-OK	2200
	Lafayette, LA	2300
	Memphis, TN-AR-MS	2300
	Monroe, LA	2300
	Montgomery, AL	2300
	New Orleans, LA	2300
	Shreveport, LA	2300
106	*Subtropical pine forest*	
	Miami, FL	4100
ALASKAN VEGETATION		
113	*Black spruce forest*	
	Anchorage, AK	1300
HAWAIIAN VEGETATION		
121	*Schlerophyllous forest-shrubland-grassland*	
	Honolulu, HI	4200

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This publication classifies 279 American metropolitan areas by ecoregion and potential natural vegetation. The classification forms a baseline of expected vegetation structure and composition that can assist scientists and policymakers in making urban forestry generalizations about classes of cities.

Keywords: urban forestry; regional ecology

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United States
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**Northeastern Forest
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Growth Response of Managed Uneven-aged Northern Conifer Stands

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Abstract

The growth response of trees in spruce-fir-hemlock stands was recorded from plots that were managed to control stand density, species composition, length of harvest interval, and salvage of mortality. Basal area, volume, and diameter increment are presented by species and size classification for harvesting intervals of 5, 10, and 20 years.

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Introduction

As landowners intensify forest management, silvicultural decisions need to be based on reliable growth information. Natural spruce-fir stands growing on good locations are capable of fast growth with high levels of growing stock (Hughes 1970). However, mortality may occur in these stands and usable volume may be lost. The growth response of a forest stand depends on the degree and type of management it receives. As a result of management practices, growth responses may vary by size class for differences in species composition, levels of density, and length of harvesting interval. The silvicultural treatment then becomes a basis upon which the forest manager is able to decide on the type and amount of growing stock that will produce the desired growth response.

A study was established in uneven-aged spruce-fir-hemlock stands in the Penobscot Experimental Forest, Bradley, Maine to determine the growth response of northern conifer stands to different levels of management. Permanent plots were located throughout these stands to monitor the growth response.

Methods

The plots selected for analysis had similar species compositions: predominantly red spruce, *Picea rubens* Sarg.; balsam fir, *Abies balsamea* (L.) Mill.; Eastern hemlock, *Tsuga canadensis* (L.) Carr.; white spruce, *Picea glauca* (Moench) Voss; and black spruce, *Picea mariana* (Mill.) B.S.P.. Associated species are white cedar, *Thuja occidentalis* L., and white pine, *Pinus strobus* L., with less than 25 percent hardwoods, red maple *Acer rubrum* L., and paper birch, *Betula papyrifera* Marsh. (Table 1). The soils within the study area are complexes of well-drained to poorly drained soils. Marlow, Peru, and

Table 1.—Species composition after initial treatment (in percent of basal area)

Residual basal area[a]	Harvest interval	Number of plots	Balsam fir			Spruces			Eastern hemlock			Other softwood			Hardwoods		
			Pole-timber	Saw-timber	Stand total	Pole-timber	Saw-timber	Stand total	Pole-timber	Saw-timber	Stand total	Pole-timber	Saw-timber	Stand total	Pole-timber	Saw-timber	Stand total
ft²/acre	*Years*																
	5	12	13.7	0.0	13.7	12.1	3.0	15.2	22.9	16.3	39.2	9.5	6.3	15.8	12.8	3.3	16.1
40	10	21	25.3	.0	25.3	10.9	7.2	18.1	8.2	14.0	22.2	13.0	5.6	18.6	14.2	1.7	15.9
	20	21	14.8	.0	14.8	11.1	2.2	13.3	20.0	11.9	31.9	20.0	3.7	23.7	14.1	2.2	16.3
	5	42	12.1	.1	12.3	7.0	7.8	14.7	17.5	24.4	41.9	11.1	2.5	13.5	12.4	5.2	17.6
60	10	54	16.2	.0	16.2	14.8	11.1	25.9	15.5	15.9	31.4	12.6	2.0	14.6	10.3	1.7	11.9
	20	39	14.8	.0	14.8	12.4	4.4	16.8	18.0	14.0	32.0	14.8	3.6	18.4	14.8	3.2	18.0
	5	65	7.6	.1	7.7	9.2	12.4	21.6	16.3	25.3	41.6	10.9	3.2	14.1	11.2	3.8	15.0
80	10	84	14.5	.0	14.5	12.7	10.6	23.3	16.6	21.2	37.8	9.2	2.3	11.5	9.5	3.4	12.9
	20	51	11.4	.0	11.4	16.3	10.4	26.7	18.4	19.3	37.7	11.0	3.4	14.4	8.0	1.8	9.8
	5	88	6.9	.1	7.1	9.9	9.2	19.1	18.1	26.8	44.9	8.9	3.9	12.8	11.6	4.5	16.1
100	10	43	8.8	.3	9.1	13.1	13.0	26.1	18.0	25.1	43.1	10.9	2.3	13.1	5.9	2.8	8.6
	20	30	9.8	.0	9.8	14.5	10.9	25.4	13.5	23.8	37.3	11.9	4.2	16.1	8.3	3.1	11.4
	5	47	6.8	.0	6.8	10.0	8.9	18.9	20.0	27.8	47.9	5.7	7.2	12.9	9.5	3.9	13.5
120	10	19	1.9	.0	1.9	9.6	10.3	19.9	27.9	24.9	52.8	10.1	3.9	14.0	8.8	2.6	11.4
	20	9	5.1	.0	5.1	8.5	10.1	18.6	22.0	33.9	55.9	10.2	3.9	13.6	3.4	3.4	6.8

[a] For conversion to square meters per hectare multiply by 0.229568.

Monarda are the most common well-drained to poorly drained soils on glacial till. Buxton, Stantic, and Biddeford are examples of moderately well-drained to poorly drained soils on marine sediments.

A total of 359 one-fifth-acre circular plots were randomly located over similar site conditions in the treated forest stands. Trees were initially marked to remove large diameter trees and nonmerchantable, overmature, and poor quality trees. Harvesting began in 1953, using an interval of 5, 10, or 20 years. The remaining trees were remeasured every 5 years, and before and after harvesting (Frank and Blum 1978).

The number of plots used for analysis was:

Interval	*No.*
20 years	150
10 years	127
5 years	75
Total	352

After each harvest, plots were recategorized by residual basal area class to obtain an average growth response for the next harvesting interval. This reorganization of plots resulted in a total of 645 harvest-interval plots for analysis. Trees 4.5 inches and larger in dbh were measured and placed in 1-inch diameter classes and in condition categories: growing stock, ingrowth, or mortality.

The basal area at each inventory was computed for trees 4.5 inches and larger. Each plot was placed in a residual basal area class, from 40 to 120 square feet, by 20-square-foot increments. The mean annual growth rate was then determined for each harvesting interval. The basal area and volume growth were averaged across the plots in each residual basal area class.

Only trees 4.5 inches dbh and larger were used to compute basal area and volume per acre. Volume growth was estimated from local volume tables for the merchantable volume of the tree. Merchantable volume is the volume of the bole from a 1-foot stump to a 4-inch top. An analysis of variance was completed for basal area, volume, and mean stand diameter growth components by residual basal area classes for each harvesting interval, species, and size class of poletimber (4.5 to 9.5 inches dbh) and sawtimber (9.5+ inches dbh). The plots ranged from 20 to 50 percent sawtimber with an average of 40 percent for all plots combined.

The growth components of interest in this paper have been defined (Gilbert 1954; Beers 1962; Marquis and Beers 1969; Solomon 1977). They are:

1. Survivor growth: Growth of trees present at both inventories

2. Ingrowth: Basal area or volume of trees that grew into measurable size between inventories

3. Gross growth: Total growth produced by all trees during the period (net growth + mortality)

4. Net growth: The net change in trees between two inventories (survivor growth + ingrowth − mortality)

5. Mortality: Trees that died during the measurement period (excluding ingrowth trees that died)

6. Accretion: Growth of trees present at the initial inventory plus growth on ingrowth, mortality and harvested trees.

Accretion was not used because trees were not marked and growth recorded for individual trees. Thus, the accretion on harvested and mortality trees could not be determined. The accretion on these trees was combined into mortality. Also, the accretion on ingrowth trees was included in ingrowth because the diameter measurement classes used were broad.

Results

Gross Growth

Average annual gross growth in basal area and volume per acre remained relatively constant over a range of residual basal areas and different harvesting intervals (Tables 2a and 2b). Gross growth increased slightly as the harvesting interval increased. The increase of 2.72 to 3.47 square feet was significant as both the residual basal area in the stand and the length of harvesting interval changed (Tables 2a and 2b). This increase may be due in part to the retention of sawtimber-size trees in the higher basal area classes. The merchantable volume of 52 to 70 cubic feet per acre per year is comparable to the gross growth of other softwood stands in the spruce-fir region of New England (Safford 1968). And, depending upon which volume tables or equations were used, differences in merchantable volume estimates can be expected (Bickford et al. 1961, Hart 1964).

Net Growth

Average annual net growth, expressed in square feet of basal area and cubic foot volume for all species, was significantly different for the different residual basal area classes and harvest intervals (Table 2a). The net growth of the total stand was between 2 and 3 square feet and differed significantly as the residual basal area and harvest interval increased. Also, when trees on plots were separated by size class, poletimber net growth decreased and sawtimber net growth increased significantly as residual

Table 2a.—Average annual gross growth, net growth, survivor growth, ingrowth, and mortality by size class, residual basal area, and harvest interval (in square feet of basal area per acre)[a]

Residual Basal Area	Harvest Interval	Gross Growth	Net Growth			Survivor Growth			Ingrowth		Mortality		
			Pole-timber	Saw-timber	Stand total	Pole-timber	Saw-timber	Stand total	Pole-timber	Saw-timber	Pole-timber	Saw-timber	Stand total
ft²/acre	*Years*												
	5	3.22	1.78	1.39	3.17	1.58	0.61	2.19	1.03	0.79	0.05	0.00	0.05
40	10	2.72	1.05	.92	1.96	1.27	.37	1.64	1.08	.64	.67	.09	.76
	20	3.25	1.23	1.63	2.86	1.53	.58	2.11	1.14	1.08	.36	.03	.39
	5	3.23	1.06	1.68	2.74	1.43	.71	2.14	1.09	1.04	.41	.07	.49
60	10	3.12	1.01	1.53	2.54	1.52	.63	2.15	.97	1.00	.48	.10	.58
	20	3.28	.96	1.71	2.67	1.65	.66	2.31	.97	1.16	.49	.11	.60
	5	3.19	.59	1.92	2.50	1.41	.98	2.40	.80	1.05	.58	.11	.70
80	10	3.15	.63	1.76	2.38	1.51	.85	2.36	.79	1.10	.57	.19	.76
	20	3.27	.58	2.03	2.61	1.57	.92	2.49	.79	1.28	.50	.16	.66
	5	3.28	.40	2.29	2.70	1.46	1.11	2.57	.72	1.30	.47	.11	.58
100	10	3.27	.19	2.39	2.58	1.53	1.06	2.59	.68	1.54	.49	.20	.68
	20	3.23	.43	2.15	2.58	1.42	1.12	2.53	.70	1.15	.53	.12	.65
	5	3.47	.39	2.32	2.71	1.65	1.17	2.81	.67	1.35	.56	.19	.75
120	10	3.04	.09	2.23	2.32	1.44	1.04	2.48	.56	1.43	.50	.22	.72
	20	3.13	–.09	2.72	2.63	1.17	1.56	2.72	.40	1.33	.33	.17	.49

[a] For conversion to square meters per hectare multiply by 0.229568.

Table 2b.—Average annual gross growth, net growth, survivor growth, ingrowth, and mortality by size class, residual basal area, and harvest interval (in merchantable cubic feet per acre—excluding bark, 1-foot stump, and 4-inch top)[a]

Residual Basal Area[b]	Harvest Interval	Gross Growth	Net growth			Survivor Growth			Ingrowth		Mortality		
			Pole-timber	Saw-timber	Stand total	Pole-timber	Saw-timber	Stand total	Pole-timber	Saw-timber	Pole-timber	Saw-timber	Stand total
ft²/acres	*Years*												
	5	60.35	30.64	29.00	59.64	32.20	14.67	46.87	13.48	14.38	0.70	0.00	0.70
40	10	52.13	18.58	20.36	38.94	28.74	9.29	38.03	14.10	12.71	11.56	1.63	13.19
	20	62.54	22.02	33.83	55.85	33.71	14.03	47.74	14.80	20.48	6.10	.58	6.68
	5	61.15	17.62	35.20	52.82	29.87	17.56	47.43	13.77	19.22	6.83	1.49	8.32
60	10	62.02	18.63	33.29	51.92	33.36	16.18	49.54	12.53	19.25	8.02	2.08	10.10
	20	63.96	17.81	35.52	53.33	35.72	15.97	51.69	12.28	21.90	8.29	2.33	10.62
	5	63.80	10.29	41.54	51.83	29.71	24.51	54.22	9.67	19.62	9.40	2.57	11.97
80	10	64.40	12.20	38.68	50.88	32.95	21.65	54.60	9.82	20.99	9.57	3.96	13.53
	20	68.46	11.74	44.72	56.46	34.76	23.65	58.41	10.08	24.75	8.40	3.59	11.99
	5	66.22	6.48	49.61	56.09	30.26	27.53	58.04	8.43	24.45	7.76	2.37	10.13
100	10	68.70	4.63	51.94	56.57	33.39	26.94	60.32	8.34	29.13	8.00	4.13	12.13
	20	68.72	8.94	48.26	57.20	31.33	28.65	59.98	8.74	22.07	9.06	2.46	11.52
	5	70.14	7.10	49.12	56.22	33.58	28.88	62.83	7.68	24.68	9.48	4.44	13.92
120	10	61.94	.97	48.50	49.47	29.07	26.39	55.46	6.44	26.47	8.10	4.35	12.45
	20	68.81	.35	60.11	60.46	24.73	39.15	63.88	4.92	24.32	5.01	3.34	8.35

[a] For conversion to cubic meters per hectare multiply by 0.069973.
[b] For conversion to square meters per hectare multiply by 0.229568.

basal area increased (Fig. 1 and 2). Although there are statistically significant differences among harvest intervals, no direct relationship was apparent for the total stand or when trees were separated by size classes. The difference between poletimber growth and sawtimber growth was less for the 10-year harvest interval than for the other two intervals.

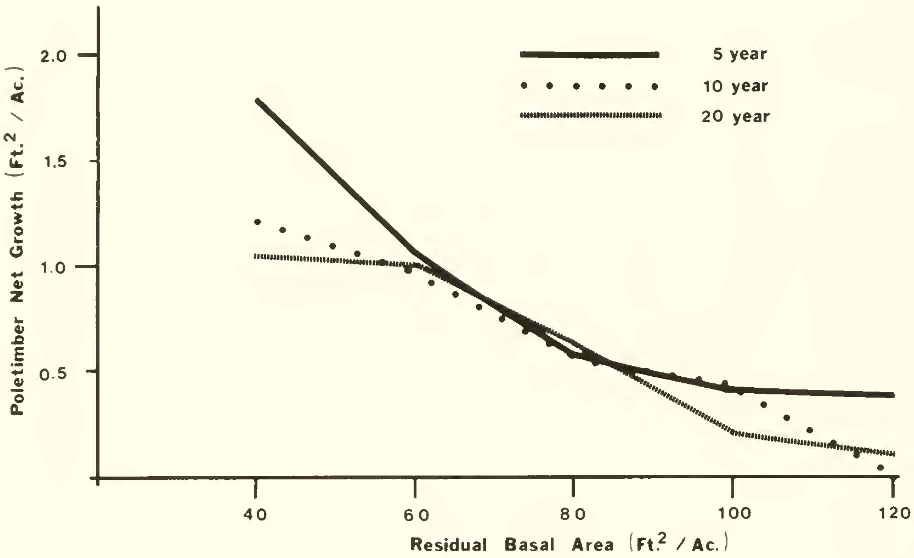


Figure 1.—Average annual poletimber net growth for 5-, 10-, and 20-year harvest intervals by residual basal area.

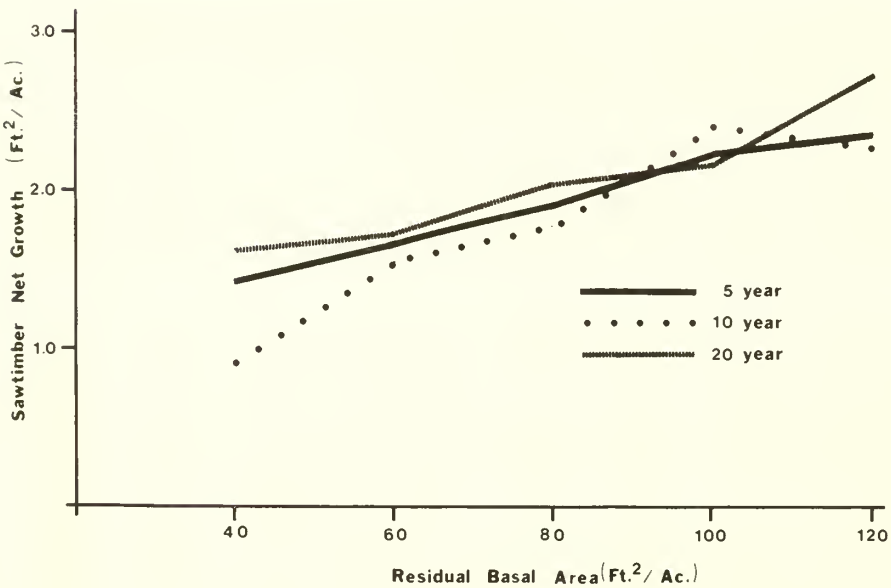


Figure 2.—Average annual sawtimber net growth for 5-, 10-, and 20-year harvest intervals by residual basal area.

Changes in net growth rate similar to those in basal area growth appeared when growth was expressed in volume per acre (Table 2b). The annual merchantable net growth rate of 50 to 60 cubic feet is comparable to the net growth per acre per year reported in other studies (Frayer and Barnard 1966; Bickford et al. 1961; Safford 1968; Frank and Blum 1978). Hart (1964) indicated a higher annual volume growth—70 cubic feet—for a similar residual basal area of 100 to 120 square feet than is reported in this and the other studies. As the residual basal area increases, more large trees are retained as growing stock. This causes the increase in the net growth rate of the sawtimber and the decrease in net growth rate of the poletimber. These changes in growth rate are caused by both a decrease in the number of trees reaching poletimber size and an increase in the number of poletimber-sized trees growing into the sawtimber size class.

Survivor Growth

Average annual survivor growth in both basal area and volume increased significantly as residual basal area increased (Tables 2a and 2b). The growth increase of the total stand from approximately 1.6 to 2.8 square feet was due largely to the increase in sawtimber survivor growth (Fig. 3). This increase appears to continue beyond 120 square feet of residual basal area. The survivor growth in poletimber remained stable over the range of residual basal areas (Fig. 4). The higher residual basal areas had larger trees and a larger proportion of sawtimber, as indicated by volume growth (Table 2b). Our total

Figure 3.—Average annual sawtimber survivor growth for 5-, 10-, and 20-year harvest interval by residual basal area.

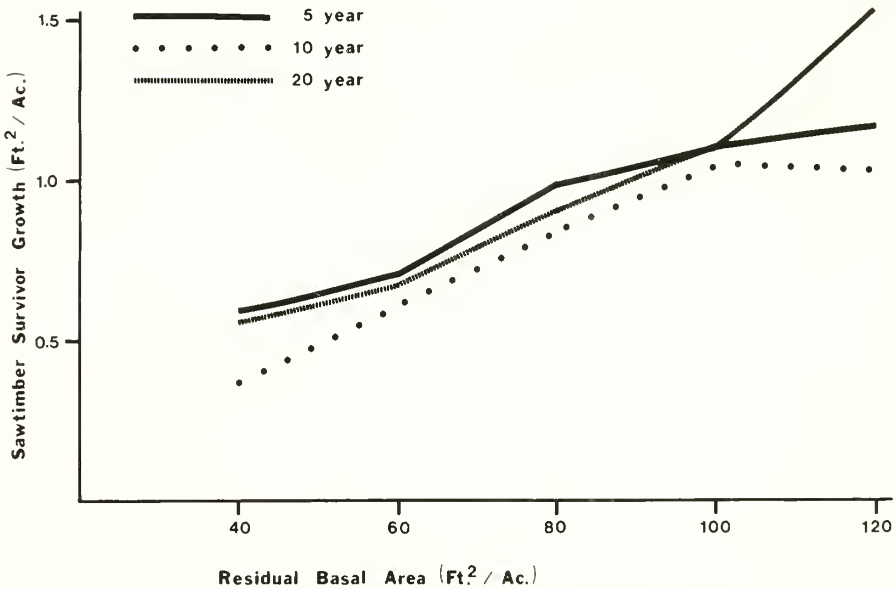
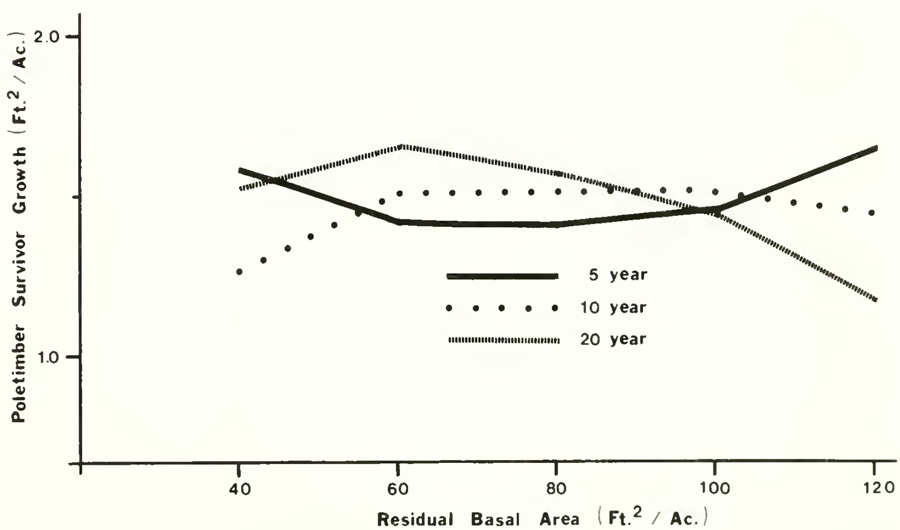


Figure 4.—Average annual poletimber survivor growth for 5-, 10-, and 20-year harvest intervals by residual basal area.



survivor growth response of 40 to 65 cubic feet over a range of densities is similar to the increasing growth rates reported by Safford (1968). This growth rate can increase up to an optimum density of 180 square feet of residual basal area (Brann et al. 1981; Solomon et al. 1982). Our annual survivor growth is higher than that found in large areas, possibly because of differences in species (Safford 1968; Bickford et al. 1961). Survivor growth did not follow a definite pattern as the length between harvests increased, although a significant difference between harvest intervals was found. It was usually less at the 10-year interval than at the other two intervals.

Ingrowth

The poletimber ingrowth for the stand decreased significantly as the residual basal area increased (Table 2a). The ingrowth into the 4.5-inch diameter class at the lower residual basal areas was approximately twice the ingrowth at the higher levels of basal area (Fig. 5). As the length of harvesting interval increased, average annual ingrowth did not change significantly. The annual poletimber ingrowth of 5 to 15 merchantable cubic feet is slightly higher than the 10-year average ingrowth reported for the spruce-fir region of northern New England over a range of densities (Safford 1968) (Table 2b). The ingrowth in Safford's study remained the same as the expression of stand density increased. However, our volume ingrowth at lower densities is approximately three times the ingrowth in Safford's study at higher densities. This may be because residual basal area expresses density differently from crown closure.

The sawtimber ingrowth (trees reaching 9.5 inches dbh) increases with an increase of residual basal area (Fig. 6). This increase was similar for all harvest intervals.

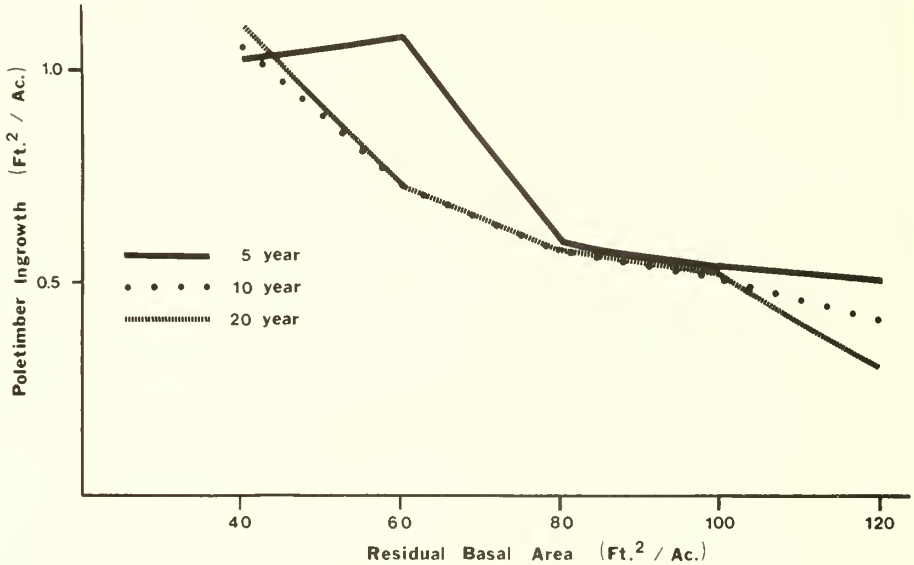


Figure 5.—Average annual poletimber ingrowth for 5-, 10-, and 20-year harvest intervals by residual basal area.

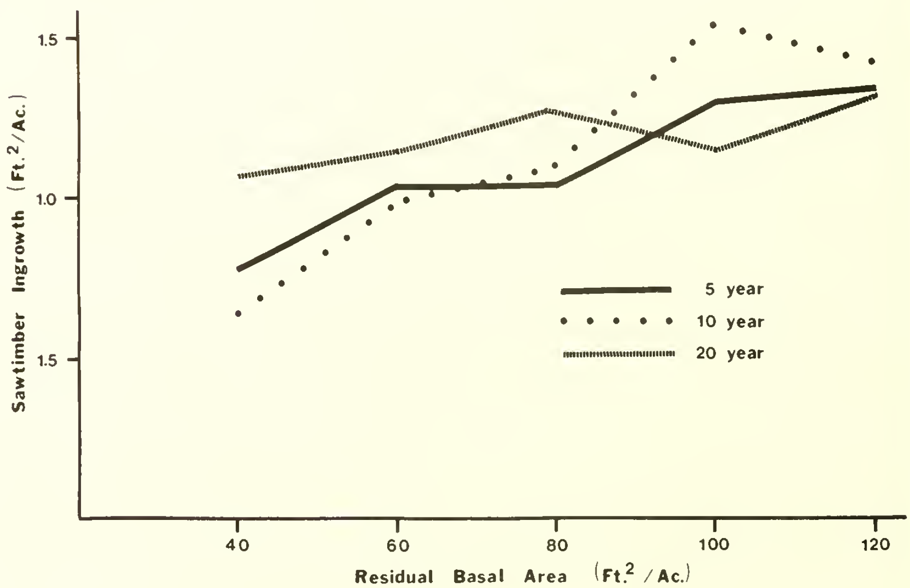


Figure 6.—Average annual sawtimber ingrowth for 5-, 10-, and 20-year harvest intervals by residual basal area.

Mortality

As expected, mortality increased significantly up to 14 cubic feet with increases in the residual basal area (Tables 2a and 2b). The differences in annual mortality between basal area levels were not large for either poletimber or sawtimber (Fig. 7 and 8). This may be because northern conifer stands can sustain higher levels of growing stock than some other timber types. The sawtimber mortality was less than the poletimber mortality, primarily because of the amount of balsam fir in the smaller diameter classes (Table 1) and to the harvesting prescriptions that remove larger trees. Balsam fir, being a short-lived species, tends to die out as the stand matures (Hart 1964). Also ingrowth trees that died during the harvest interval were ignored in this study. This may make poletimber mortality estimates lower in the higher basal area classes.

No pattern of increased mortality appeared as the length of harvest interval increased. It was expected that the 5-year harvesting interval would reduce mortality by harvesting trees that might die during a longer harvesting interval. However, the mortality was not significantly less for the shorter interval.

Stand Growth

The type of management practiced, even-age or uneven-age, determines the silviculture treatments and resulting growth rates. The objective of even-age management is to encourage the growth of overstory trees, which is best done by removing the old stand completely to establish a new stand.

One objective of uneven-age management is to produce a consistant product flow as trees mature. This is best accomplished by selecting trees for removal to maintain optimum growing space. The manager can also improve the spe-

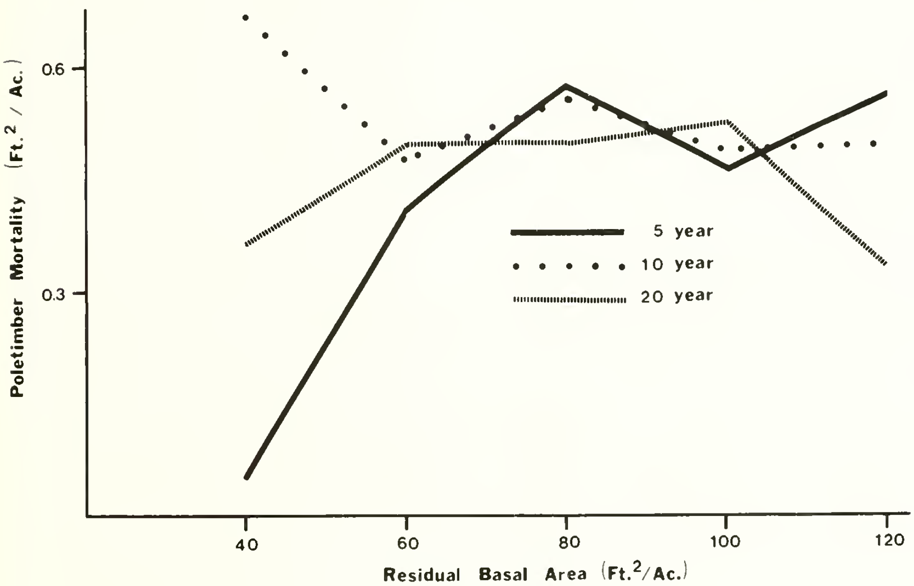


Figure 7.—Average annual poletimber mortality for 5-, 10-, and 20-year harvest intervals by residual basal area.

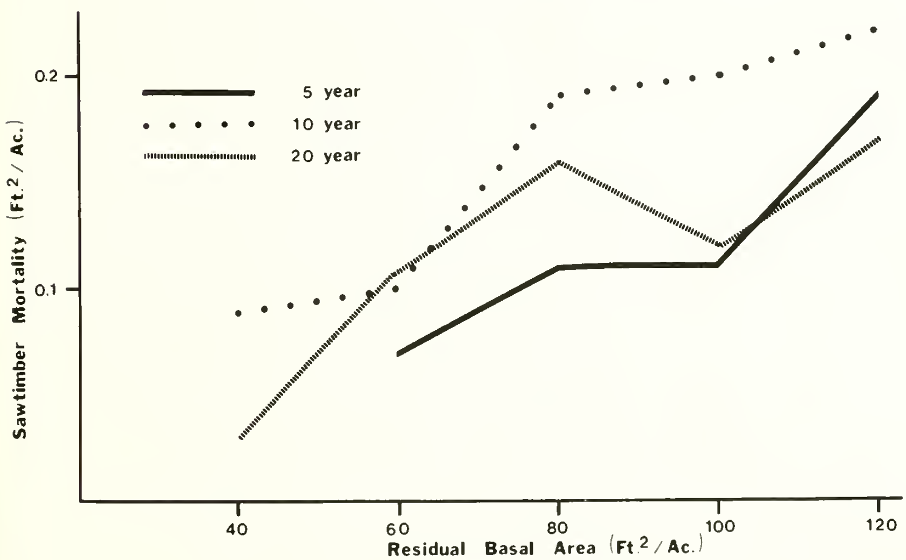


Figure 8.—Average annual sawtimber mortality for 5-, 10-, and 20-year harvest intervals by residual basal area.

cies composition and quality of products by retaining the larger, more valuable trees in the remaining stand. Since a continuous supply of sawlogs is frequently the product goal of uneven-age management, this harvesting practice must leave enough understory trees to grow into sawtimber trees and enough sawtimber trees at the desired density to maintain optimum growing stock.

In order to maintain this flow of products, an adequate amount of poletimber ingrowth is needed to balance mortality. However, if poletimber ingrowth is too high, it may be necessary to remove some of the smaller trees to provide enough growing space for the remaining trees. Thus, size classes of trees should be kept in balance to maintain optimum growth rate.

By keeping the stand at the optimum residual basal area, it is possible to establish and maintain an adequate product flow and have the ingrowth and mortality in balance. This results in a poletimber net growth near zero. Within the limits of this study, the optimum residual basal area density to accomplish this management is 120 square feet or more for a spruce-fir stand with 45 percent sawtimber. Harvest intervals of both 10 and 20 years have high sawtimber survivor growth with a balance of poletimber mortality and ingrowth.

Growth Rates by Species

Annual survivor growth in basal area and volume by species, size class, and residual basal area are shown in Tables 3a and 3b. Annual survivor growth significantly changed as the residual basal area and harvest interval increased for all species. Annual growth of balsam fir decreased as basal area increased, probably because there was a higher proportion of fir poletimber and less fir in the total species composition at the higher residual basal areas (Table 1). Fir, a shorter-lived species, was harvested more intensively at small diameters than longer-lived species such as spruce or hemlock. Balsam fir and spruce had higher annual survivor growth as the harvest interval increased. The survivor growth rate of hemlock and hardwoods decreased as the interval lengthened, perhaps because hemlock and hardwoods can respond more quickly to the removal of a portion of the growing stock. Spruce and fir seem to respond more slowly, especially at longer harvest intervals.

In order to compare the rate of growth between species and basal area classes, the annual survivor growth was calculated as a percentage of the initial basal area or volume in each class (Tables 4a and 4b). Poletimber consistently had a greater growth response than sawtimber (Figs. 3 and 4). Balsam fir and hardwood poletimber outgrew the other species in the lower basal area classes. Hemlock and spruce had the best sawtimber survivor growth as the residual basal area increased. Although no definite pattern emerged when survivor growth was expressed as a percentage of initial basal area, the percentages seemed to decrease as the residual basal area increased. However, the percentages increased as the harvest interval increased for most species except hemlock poletimber and hardwood sawtimber.

Annual mortality of species by basal area classes did not change for the different harvesting intervals (Tables 5a and 5b). The greatest mortality was in balsam fir poletimber—about 6 cubic feet per acre per year. Mortality increased up to a residual basal area of 80 square feet and then declined because the proportion of fir in the species composition declined. In general, poletimber had slightly higher mortality than sawtimber when mortality was expressed as basal area (Table 5a). Annual mortality expressed in cubic feet, however, is higher for taller sawtimber trees because they have proportionally more merchantable volume in the bole than poletimber trees.

When annual mortality per acre is expressed as a percentage of initial basal area, it is small in managed stands (Tables 6a and 6b). Although there is a general increase in the proportion of mortality as the residual basal area increases, no real pattern of mortality is evident either for basal area level or for harvest interval. Except for balsam fir, the annual mortality among species is very similar and demonstrates an even utilization of all sizes of trees during harvest. The percentage mortality of spruce is greater than that of hemlock for both poletimber and sawtimber.

Table 3a.—Annual survivor growth by species, size class, residual basal area, and harvest interval (in square feet of basal area per acre)[a]

Residual Basal Area	Harvest Interval	Balsam Fir Pole-timber	Balsam Fir Saw-timber	Spruces Pole-timber	Spruces Saw-timber	Eastern Hemlock Pole-timber	Eastern Hemlock Saw-timber	Other Softwoods Pole-timber	Other Softwoods Saw-timber	Hardwoods Pole-timber	Hardwoods Saw-timber
ft²/acre	*Years*										
	5	0.47	0.00	0.33	0.06	0.50	0.32	0.09	0.14	0.19	0.09
40	10	.43	.00	.22	.12	.16	.17	.12	.05	.34	.04
	20	.43	.00	.23	.11	.39	.37	.16	.05	.33	.04
	5	.30	.00	.18	.11	.49	.49	.16	.03	.30	.08
60	10	.32	.00	.33	.22	.44	.34	.15	.04	.28	.03
	20	.33	.01	.28	.14	.47	.38	.17	.07	.40	.06
	5	.19	.00	.26	.26	.54	.59	.13	.08	.30	.06
80	10	.31	.00	.32	.26	.46	.49	.12	.03	.29	.07
	20	.31	.00	.40	.30	.50	.52	.11	.08	.26	.02
	5	.13	.00	.29	.23	.58	.69	.12	.08	.33	.11
100	10	.20	.01	.36	.28	.60	.64	.15	.05	.22	.08
	20	.23	.00	.36	.33	.42	.64	.14	.10	.26	.05
	5	.11	.01	.31	.19	.78	.64	.09	.21	.37	.11
120	10	.07	—	.19	.27	.83	.62	.10	.08	.26	.08
	20	.14	.00	.20	.33	.63	1.12	.06	.08	.14	.03

[a]For conversion to square meters per hectare multiply by 0.229568.

Table 3b.—Annual survivor growth by species, size class, residual basal area, and harvest interval (in merchantable cubic feet per acre—excluding bark, 1-foot stump, and 4-inch top)[a]

Residual Basal Area[b]	Harvest Interval	Balsam Fir Pole-timber	Balsam Fir Saw-timber	Spruces Pole-timber	Spruces Saw-timber	Eastern Hemlock Pole-timber	Eastern Hemlock Saw-timber	Other Softwoods Pole-timber	Other Softwoods Saw-timber	Hardwoods Pole-timber	Hardwoods Saw-timber
ft²/acre	*Years*										
	5	10.24	0.07	8.05	1.56	8.73	7.44	1.82	3.85	3.36	1.75
40	10	10.81	.01	5.82	3.52	2.85	4.01	2.59	.86	6.68	.88
	20	10.45	.08	6.13	3.26	7.19	8.84	3.33	1.06	6.61	.79
	5	6.95	.01	4.75	3.34	8.96	11.66	3.32	.77	5.88	1.78
60	10	7.96	.04	8.53	6.44	8.06	8.11	3.32	.87	5.49	.72
	20	8.07	.23	7.43	4.02	8.63	9.17	3.73	1.86	7.86	.69
	5	4.51	.00	6.77	7.36	9.77	14.05	2.70	1.76	5.97	1.33
80	10	7.64	.04	8.53	7.62	8.51	11.64	2.49	.80	5.78	1.55
	20	7.53	.05	10.45	8.66	9.32	12.50	2.42	2.01	5.04	.43
	5	3.18	.10	7.66	6.51	10.49	16.50	2.55	2.03	6.37	2.39
100	10	5.08	.19	9.59	8.22	11.02	15.59	3.28	1.11	4.42	1.83
	20	5.80	.03	9.50	9.45	7.83	15.60	3.10	2.43	5.11	1.14
	5	2.62	.25	8.03	5.63	14.07	15.30	1.86	5.26	7.00	2.44
120	10	1.71	—	5.39	7.63	14.80	14.98	2.06	1.99	5.11	1.79
	20	3.37	.01	5.58	9.45	11.64	27.16	1.36	1.83	2.77	.71

[a] For conversion to cubic meters per hectare multiply by 0.069973.
[b] For conversion to square meters per hectare multiply by 0.229568.

Table 4a.—Annual survivor growth by species, size class, residual basal area, and harvest interval (in percent of initial basal area)

Residual Basal Area[a]	Harvest Interval	Balsam Fir		Spruces		Eastern Hemlock		Other Softwoods		Hardwoods	
		Pole-timber	Saw-timber	Pole-timber	Saw-timber	Pole-timber	Saw-timber	Pole-timber	Saw-timber	Pole-timber	Saw-timber
ft²/acre	*Years*										
	5	6.96	0.00	6.06	0.97	6.03	3.63	1.74	1.39	5.11	3.80
40	10	7.42	.00	5.42	1.88	3.01	1.36	2.15	.66	7.69	1.44
	20	8.44	.00	3.82	1.83	4.47	3.54	1.39	.89	8.18	.74
	5	5.02	.00	3.77	1.88	4.15	2.72	1.82	.40	4.55	1.10
60	10	5.35	.00	3.17	3.09	3.83	2.12	1.63	.77	4.77	.52
	20	8.68	.25	4.66	2.74	5.44	4.01	2.17	.88	4.57	.81
	5	4.00	.00	3.21	2.26	4.46	2.51	1.32	.93	3.75	1.07
80	10	3.37	.01	3.72	2.34	3.37	2.18	1.29	.63	4.31	1.07
	20	4.54	.00	3.36	3.81	3.47	3.02	1.20	1.19	4.15	.41
	5	2.34	.02	2.76	2.23	3.80	2.53	1.10	.70	3.31	1.91
100	10	3.31	.39	2.94	2.14	3.50	2.45	1.23	.60	3.93	1.13
	20	3.01	.03	2.86	2.75	3.49	2.14	1.17	1.00	4.03	.86
	5	.68	.00	2.59	1.60	3.34	2.16	.93	1.41	3.81	1.71
120	10	1.58	—	1.81	2.83	2.74	1.85	.74	1.17	2.83	.97
	20	2.78	.00	2.48	3.05	2.79	2.75	.36	1.07	4.59	.76

[a]For conversion to square meters per hectare multiply by 0.229568.

Table 4b.—Annual survivor growth by species, size class, residual basal area, and harvest interval (in percent of initial volume)

Residual Basal Area[a]	Harvest Interval	Balsam Fir		Spruces		Eastern Hemlock		Other Softwoods		Hardwoods	
		Pole-timber	Saw-timber	Pole-timber	Saw-timber	Pole-timber	Saw-timber	Pole-timber	Saw-timber	Pole-timber	Saw-timber
ft²/acre	*Years*										
	5	9.27	0.00	8.48	1.22	8.11	4.55	2.20	1.77	5.77	3.87
40	10	9.97	.00	9.71	2.34	4.20	1.79	3.26	.66	10.65	1.75
	20	12.49	.00	6.26	2.23	6.27	4.82	2.02	.98	14.79	.99
	5	6.89	.00	5.61	2.30	5.56	3.53	2.47	.45	5.99	1.30
60	10	7.93	.00	4.80	3.70	5.36	2.77	2.45	.96	6.98	.65
	20	12.45	.28	7.71	3.38	7.78	5.37	3.18	1.04	6.74	.87
	5	5.64	.00	4.91	2.68	6.06	3.25	2.01	.99	5.16	1.32
80	10	5.02	.01	4.16	2.80	4.46	2.85	1.88	.77	6.14	1.37
	20	6.69	.00	5.08	4.67	4.87	4.10	1.72	1.44	5.85	.51
	5	3.38	.03	4.20	2.63	5.03	3.25	1.65	.81	4.43	2.30
100	10	4.83	.44	4.44	2.56	4.85	2.24	1.81	.68	5.68	1.42
	20	4.51	.04	4.40	3.33	4.77	2.84	1.78	1.17	5.42	1.10
	5	1.04	.00	3.95	1.96	4.53	2.76	1.14	1.62	4.93	2.10
120	10	2.48	—	2.68	3.26	3.70	2.47	1.08	1.38	3.71	1.23
	20	4.25	.00	4.26	3.78	3.83	3.66	.53	1.10	7.11	.96

[a] For conversion to square meters per hectare multiply by 0.229568.

Table 5a.—Annual mortality by species, size class, residual basal area, and harvest interval (in square feet of basal area per acre)[a]

Residual Basal Area	Harvest Interval	Balsam Fir		Spruces		Eastern Hemlock		Other Softwoods		Hardwoods	
		Pole-timber	Saw-timber	Pole-timber	Saw-timber	Pole-timber	Saw-timber	Pole-timber	Saw-timber	Pole-timber	Saw-timber
ft²/acre	*Years*										
	5	0.03	—	0.01	—	0.01	—	—	—	—	—
40	10	.54	—	.03	—	.01	0.05	0.05	0.04	0.04	—
	20	.22	0.01	.04	0.01	.02	—	.03	.01	.06	0.01
	5	.26	—	.02	.03	.03	—	.08	.04	.03	—
60	10	.29	.01	.05	.03	.05	.03	.03	.01	.06	.03
	20	.34	—	.05	.03	.02	.04	.03	.03	.05	.02
	5	.33	—	.05	.04	.05	.03	.11	.02	.04	.02
80	10	.36	.01	.05	.04	.06	.13	.06	.00	.04	01
	20	.31	.01	.07	.05	.04	.03	.05	.03	.04	.04
	5	.29	.01	.05	.03	.02	.02	.07	.06	.04	.01
100	10	.29	—	.04	.07	.05	.08	.09	.03	.02	.02
	20	.32	.02	.07	.02	.02	.06	.07	—	.05	.02
	5	.33	—	.06	.10	.05	.03	.08	.06	.05	—
120	10	.07	—	.11	.03	.16	.14	.11	.04	.05	.02
	20	.12	.02	.03	.03	.04	.03	.09	.08	.04	.02

[a] For conversion to square meters per hectare multiply by 0.229568.

Table 5b.—Annual mortality by species, size class, residual basal area, and harvest interval (in merchantable cubic feet per acre—excluding bark, 1-foot stump, and 4-inch top)[a]

Residual Basal Area[b]	Harvest Interval	Balsam Fir		Spruces		Eastern Hemlock		Other Softwoods		Hardwoods	
		Pole-timber	Saw-timber	Pole-timber	Saw-timber	Pole-timber	Saw-timber	Pole-timber	Saw-timber	Pole-timber	Saw-timber
ft²/acre	*Years*										
	5	0.43	—	0.18	—	0.10	—	—	—	—	—
40	10	9.69	—	.49	—	.14	0.92	0.78	0.71	0.47	—
	20	3.97	0.16	.61	0.19	.33	—	.37	.13	.83	0.10
	5	4.70	—	.37	.69	.42	—	.99	.80	.36	—
60	10	5.24	.15	.90	.66	.67	.63	.39	.19	.82	.45
	20	6.09	—	.83	.77	.29	.75	.45	.50	.63	.32
	5	5.73	—	.87	1.04	.66	.68	1.56	.56	.59	.29
80	10	6.38	.23	.91	.99	.78	2.50	.90	.07	.61	.17
	20	5.51	.26	1.18	1.20	.54	.60	.65	.58	.54	.96
	5	4.99	.15	.87	.65	.28	.34	1.03	1.14	.60	.09
100	10	5.17	—	.65	1.68	.64	1.55	1.29	.52	.25	.39
	20	5.75	.39	1.24	.48	.28	1.09	1.02	—	.77	.50
	5	5.88	—	.92	2.51	.68	.56	1.21	1.37	.79	—
120	10	1.37	—	2.14	.66	2.23	2.67	1.63	.72	.73	.31
	20	2.23	.37	.41	.66	.47	.57	1.25	1.48	.65	.26

[a] For conversion to cubic meters per hectare multiply by 0.069973.
[b] For conversion to square meters per hectare multiply by 0.229568.

Table 6a.—Annual mortality by species, size class, residual basal area, and harvest interval (in percent of initial basal area)

Residual Basal Area[a]	Harvest Interval	Balsam Fir Pole-timber	Balsam Fir Saw-timber	Spruces Pole-timber	Spruces Saw-timber	Eastern Hemlock Pole-timber	Eastern Hemlock Saw-timber	Other Softwoods Pole-timber	Other Softwoods Saw-timber	Hardwoods Pole-timber	Hardwoods Saw-timber
ft²/acre	*Years*										
	5	0.41	—	0.19	—	0.10	—	—	—	—	—
40	10	5.49	—	.24	—	.10	0.29	0.35	0.31	0.48	—
	20	2.76	0.00	.64	0.31	.17	—	.67	.24	.71	0.00
	5	2.58	—	.26	.65	.35	—	.65	.58	.37	—
60	10	2.90	.00	.38	.49	.45	.28	.45	.19	.70	.62
	20	3.55	—	.48	.67	.29	.29	.38	.32	.65	.37
	5	3.72	—	.75	.47	.40	.18	1.28	.12	.71	.15
80	10	3.18	.00	.36	.42	.30	.46	1.14	.11	.48	.09
	20	2.99	.10	.52	.54	.21	.12	.47	.36	.57	.47
	5	3.43	.00	.40	.19	.16	.04	.93	.35	.28	.06
100	10	1.74	—	.32	.41	.26	.32	.96	.33	.23	.27
	20	3.11	.50	.46	.14	.25	.16	.68	—	.97	.36
	5	4.16	—	.74	.32	.16	.07	1.39	.23	.98	—
120	10	2.79	—	1.73	.39	.48	.30	1.44	.19	.34	.67
	20	2.04	.56	.18	.10	.14	.06	1.03	1.68	1.10	.20

[a] For conversion to square meters per hectare multiply by 0.229568.

Table 6b.—Annual mortality by species, size class, residual basal area, and harvest interval (in percent of initial volume)

Residual Basal Area[a]	Harvest Interval	Balsam Fir Pole-timber	Balsam Fir Saw-timber	Spruces Pole-timber	Spruces Saw-timber	Eastern Hemlock Pole-timber	Eastern Hemlock Saw-timber	Other Softwoods Pole-timber	Other Softwoods Saw-timber	Hardwoods Pole-timber	Hardwoods Saw-timber
ft²/acre	*Years*										
	5	0.36	—	0.19	—	0.77	—	—	—	—	—
40	10	5.63	—	.26	—	.10	0.29	0.37	0.30	0.47	—
	20	3.14	0.00	.68	0.33	.18	—	.31	.24	.73	0.00
	5	2.63	—	.26	.65	.36	—	.61	.58	.36	—
60	10	3.02	.00	.38	.49	.46	.28	.45	.19	.73	.62
	20	2.69	—	.49	.69	.29	.30	.34	.30	.68	.37
	5	3.79	—	.73	.47	.41	.18	1.27	.13	.68	.13
80	10	3.32	.00	.37	.42	.31	.48	.88	.11	.48	.09
	20	3.24	.71	.50	.55	.21	.12	.44	.36	.59	.48
	5	3.45	.00	.40	1.36	.17	.05	.70	.35	.26	.06
100	10	1.84	—	.31	.41	.26	.33	.69	.33	.24	.27
	20	3.29	.50	.46	.14	.26	.16	.69	—	.84	.38
	5	4.21	—	.67	.33	.16	.08	1.45	.23	.98	—
120	10	2.89	—	1.76	.37	.50	.32	1.35	.17	.33	.69
	20	2.14	.56	.14	.11	.13	.06	.94	1.68	1.09	.19

[a] For conversion to square meters per hectare multiply by 0.229568.

The poletimber ingrowth of balsam fir, hardwoods, and other softwoods decreased significantly as the residual basal area increased (Tables 7a and 7b). Balsam fir had the most ingrowth and declined significantly as both residual basal area and harvest interval increased. This amount of fir ingrowth is more than the fir mortality (Table 5a). Hemlock and spruce ingrowth decreased significantly as the harvest interval lengthened. Both are tolerant species, and can survive even though the ingrowth rates are reduced.

Table 7a.—Average annual ingrowth of poletimber by species, residual basal area, and harvest interval (in square feet of basal area per acre)[a]

Residual Basal Area	Harvest Interval	Species				
		Balsam Fir	Spruces	Eastern Hemlock	Other Softwoods	Hardwoods
ft²/acre	*Years*					
	5	0.54	0.10	0.22	0.04	0.14
40	10	.54	.08	.09	.10	.28
	20	.56	.07	.16	.08	.27
	5	.46	.06	.21	.18	.19
60	10	.46	.10	.15	.08	.19
	20	.39	.08	.15	.09	.26
	5	.25	.06	.25	.11	.14
80	10	.30	.09	.17	.07	.16
	20	.35	.12	.11	.08	.14
	5	.16	.06	.28	.07	.16
100	10	.24	.07	.17	.08	.13
	20	.26	.07	.12	.10	.15
	5	.09	.08	.29	.03	.18
120	10	.10	.04	.24	.07	.11
	20	.12	.04	.14	.02	.08

[a] For conversion to square meters per hectare multiply by 0.229568.

Table 7b.—Average annual ingrowth of poletimber by species, residual basal area, and harvest interval (in merchantable cubic feet per acre—excluding bark, 1-foot stump, and 4-inch top)[a]

Residual Basal Area[b]	Harvest Interval	Species				
		Balsam Fir	Spruces	Eastern Hemlock	Other Softwoods	Hardwoods
ft²/acre	*Years*					
	5	7.98	1.27	2.31	0.37	1.54
40	10	8.02	.91	.95	1.02	3.20
	20	8.37	.80	1.74	.80	3.09
	5	6.89	.70	2.18	1.86	2.14
60	10	6.79	1.24	1.53	.80	2.16
	20	5.80	1.00	1.56	.92	3.02
	5	3.63	.70	2.56	1.18	1.59
80	10	4.42	1.12	1.73	.72	1.83
	20	5.17	1.39	1.18	.78	1.56
	5	2.33	.65	2.90	.72	1.84
100	10	3.56	.77	1.73	.85	1.46
	20	3.85	.86	1.25	1.04	1.74
	5	1.37	.94	3.06	.27	2.04
120	10	1.43	.49	2.48	.77	1.27
	20	1.81	.53	1.45	.23	.90

[a] For conversion to cubic meters per hectare multiply by 0.069973.
[b] For conversion to square meters per hectare multiply by 0.229568.

Average annual ingrowth into the sawtimber class increased for most species as both residual basal area and harvest interval increased (Tables 8a and 8b). The species with the largest amount of ingrowth into the sawtimber size was hemlock, followed by spruce. Spruce sawtimber ingrowth seems to have leveled off or declined between 100 and 120 square feet of basal area, while hemlock is still increasing. Stands of softwoods are able to sustain larger trees at higher densities than hardwoods.

Table 8a.—Average annual ingrowth of sawtimber by species, residual basal area, and harvest interval (in square feet of basal area per acre)[a]

Residual Basal Area	Harvest Interval	Species				
		Balsam Fir	Spruces	Eastern Hemlock	Other Softwoods	Hardwoods
ft²/acre	*Years*					
	5	0.05	0.11	0.42	0.03	0.18
40	10	.05	.22	.14	.06	.17
	20	.06	.28	.51	.11	.12
	5	.04	.22	.52	.03	.23
60	10	.03	.32	.40	.09	.16
	20	.04	.29	.53	.13	.17
	5	.02	.29	.54	.06	.16
80	10	.03	.38	.52	.05	.12
	20	.03	.47	.57	.06	.15
	5	.03	.37	.57	.06	.27
100	10	.02	.50	.76	.13	.13
	20	.03	.42	.53	.05	.13
	5	.01	.29	.77	.06	.23
120	10	—	.43	.62	.11	.27
	20	.02	.33	.88	.06	.05

[a] For conversion to square meters per hectare multiply by 0.229568.

Table 8b.—Average annual ingrowth of sawtimber by species, residual basal area, and harvest interval (in merchantable cubic feet per acre—excluding bark, 1-foot stump, and 4-inch top)[a]

Residual Basal Area[b]	Harvest Interval	Species				
		Balsam Fir	Spruces	Eastern Hemlock	Other Softwoods	Hardwoods
ft²/acre	*Years*					
	5	1.21	2.42	6.95	0.66	3.15
40	10	1.29	4.97	2.26	1.20	2.99
	20	1.39	6.57	8.52	1.93	2.08
	5	.86	5.12	8.62	.56	4.07
60	10	.76	7.53	6.58	1.62	2.76
	20	.92	6.63	8.88	2.53	2.95
	5	.37	6.67	8.84	1.02	2.71
80	10	.72	8.69	8.56	.96	2.05
	20	.70	10.67	9.61	1.16	2.60
	5	.78	8.42	9.33	1.14	4.79
100	10	.54	11.49	12.48	2.33	2.28
	20	.78	9.55	8.73	.84	2.18
	5	.28	6.68	12.62	1.11	3.99
120	10	—	9.79	10.20	1.94	4.55
	20	.37	7.63	14.44	1.09	.79

[a] For conversion to cubic meters per hectare multiply by 0.069973.
[b] For conversion to square meters per hectare multiply by 0.229568.

Diameter Growth

Since individual remeasured data were not recorded for each tree, diameter growth by species and size classes cannot be exactly determined. However, from the mean stand diameter at the beginning and end of the measurement period, excluding mortality trees, the average annual diameter growth can be approximated (Table 9).

As expected, poletimber of all species grew faster in the lower residual basal area classes and total stand diameter growth declined as the basal area increased. Balsam fir declined most in diameter growth, because of increased competition and the decreasing proportion of fir poletimber in the species composition. The diameter growth of spruce and hemlock poletimber was approximately the same.

Hemlock had the best sawtimber diameter growth. The difference was greater in the lower basal area classes where the larger hemlock trees respond to release. The diameter growth of spruce equals that of hemlock in the denser stands.

For fir, diameter growth increased as the length of harvest interval increased. However, no definite pattern was evident for the other species, which seemed to decline as the harvest interval increased. For most density classes, balsam fir is capable of more rapid growth than spruce or hemlock in the longer harvest intervals of 10 or 20 years. Fir was removed more heavily in the 5 year harvesting interval, thus fewer of the faster-growing fir were present.

Table 9.—Average annual diameter growth by species, size class, residual basal area, and harvest interval (in inches)[a]

Residual Basal Area[b]	Harvest Interval	Species														
		Balsam Fir			Spruces			Eastern Hemlock			Other Softwoods			Hardwoods		
		Pole-timber	Saw-timber	Merchantable	Pole-timber	Saw-timber	Merchantable	Pole-timber	Saw-timber	Merchantable	Pole-timber	Saw-timber	Merchantable	Pole-timber	Saw-timber	Merchantable
ft²/acre	*Years*															
40	5	0.19	0.00	0.19	0.19	0.05	0.19	0.18	0.20	0.20	0.05	0.08	0.07	0.17	0.10	0.17
	10	.23	.00	.23	.14	.09	.14	.09	.08	.09	.07	.05	.07	.17	.06	.17
	20	.27	.00	.27	.12	.04	.12	.13	.14	.14	.04	.04	.04	.16	.03	.16
60	5	.14	.00	.14	.13	.10	.11	.14	.15	.15	.05	.02	.05	.12	.06	.12
	10	.14	.00	.14	.10	.14	.12	.12	.11	.12	.05	.04	.05	.13	.02	.13
	20	.20	.01	.20	.13	.10	.13	.14	.18	.16	.06	.03	.06	.12	.03	.12
80	5	.11	.00	.11	.10	.14	.12	.14	.14	.14	.04	.06	.06	.12	.05	.12
	10	.10	.00	.10	.09	.12	.11	.11	.12	.12	.04	.03	.04	.12	.06	.12
	20	.18	.00	.18	.11	.15	.13	.10	.14	.12	.04	.06	.05	.11	.02	.11
100	5	.07	.00	.07	.10	.13	.11	.12	.15	.13	.03	.04	.04	.10	.09	.10
	10	.10	.01	.10	.10	.11	.11	.11	.13	.12	.04	.03	.04	.11	.05	.11
	20	.18	.00	.18	.09	.13	.11	.11	.11	.11	.04	.05	.05	.11	.05	.11
120	5	.03	.04	.03	.09	.09	.09	.11	.11	.11	.03	.09	.07	.13	.09	.13
	10	.04	—	.04	.07	.17	.09	.09	.10	.09	.02	.08	.05	.09	.05	.09
	20	.10	.00	.10	.08	.14	.11	.09	.14	.11	.02	.05	.04	.10	.04	.10

[a] For conversion to centimeters multiply by 2.54.
[b] For conversion to square meters per hectare multiply by 0.229568.

The average diameter of trees that died is given in Table 10. When mortality is expressed in square feet of basal area (Table 5), balsam fir poletimber had the highest annual mortality. However, fir had the smallest average diameter of trees that died (Table 10). On the average, hemlock and spruce had similar diameters for the trees that died, between 7.0 and 9.5 inches. No change in the size of trees that died was obvious as either the residual basal area or harvest interval increased.

Conclusion

The gross growth of managed northern conifer stands varied little across the different levels of residual basal area from 40 to 120 square feet. Net growth did not indicate a definite relationship as the residual basal area increased for the total stand. However, net growth of sawtimber increased as residual basal area increased. Although net growth of poletimber decreased as density increased, the increase in sawtimber more than compensated for that reduction.

Of the components of net growth, survivor growth increases as residual basal area increases. This increase is primarily due to the increase in growth rate of sawtimber. Survivor growth of poletimber remains relatively constant across density.

Poletimber ingrowth had the largest influence on net growth, since ingrowth decreases as residual basal area increases. This result influences the number of trees that grow into the lower diameter classes, affecting stand stability. The low net growth of poletimber is comparable to poletimber ingrowth and is balanced by poletimber mortality. If a residual basal area of 120 square feet or more is maintained, the sawtimber survivor growth increases, sawtimber ingrowth is high, and poletimber mortality keeps poletimber ingrowth balanced. Therefore, excess poletimber does not have to be removed to maintain desired growing stock.

Table 10.—Average diameter of trees that died by species, size class, residual basal area, and harvest interval (in inches)[a]

Residual Basal Area[b]	Harvest Interval	Species				
		Balsam Fir	Spruces	Eastern Hemlock	Other Softwoods	Hardwoods
ft²/acre	*Years*					
	5	5.80	6.00	5.76	—	—
40	10	6.20	7.40	10.40	7.37	5.19
	20	6.37	6.88	7.18	6.23	6.33
	5	6.34	8.69	7.88	6.89	6.09
60	10	6.28	8.23	8.27	6.59	6.89
	20	6.09	7.36	8.15	7.18	6.43
	5	5.86	8.05	7.28	6.76	6.42
80	10	6.19	8.13	9.53	6.01	6.56
	20	6.15	7.40	7.97	6.87	7.69
	5	5.99	7.86	8.00	6.33	6.36
100	10	6.31	8.16	7.76	6.43	7.19
	20	6.06	7.18	8.97	6.03	6.72
	5	6.08	8.14	7.43	7.03	6.82
120	10	6.47	8.42	8.59	6.55	7.63
	20	6.25	6.57	7.36	6.56	7.01

[a] For conversion to centimeters multiply by 2.54.
[b] For conversion to square meters per hectare multiply by 0.229568.

Although short-lived species such as balsam fir have rapid poletimber survivor growth in the lower basal area classes, spruce and hemlock poletimber did better at the upper levels of density. Some of this difference may be due to the decreasing proportion of fir at the higher density classes. Hemlock had the highest sawtimber survivor growth.

Mortality did not show a definite relationship to increases in density over the stands as a whole, primarily because of the intensive utilization of the shorter-lived species. Fir poletimber had the highest mortality, which influenced the low net growth, especially at the higher densities. Most species on the plots had similar annual mortality rates, except fir which had significantly higher mortality.

The greatest amount of ingrowth was also into the balsam fir poletimber class. Most species declined in ingrowth as density increased. Hemlock had the smallest increase. Hardwoods had more ingrowth than spruce and, in some instances, were second only to fir. Hemlock had the highest sawtimber ingrowth rate of the species studied. This is to be expected, since hemlock is a long-lived species and made up a large proportion of the stands. The harvest interval had very little influence on growth response. As the harvest interval increased, ingrowth declined and mortality increased slightly.

Overall diameter growth declined as the residual basal area increased, especially in balsam fir. Hemlock had the best sawtimber diameter growth, although spruce grew as fast in the higher residual levels of basal area. As harvest interval increased, the diameter growth of balsam fir increased. However, the diameter growth rate of the other species remained similar for different harvest intervals.

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Solomon, Dale S.; Frank M. **Growth response of managed uneven-aged northern conifer stands.** Res. Pap. NE-517 Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 17 p.

The growth response of trees in spruce-fir-hemlock stands was recorded from plots that were managed to control stand density, species composition, length of harvest interval, and salvage of mortality. Basal area, volume, and diameter increment are presented by species and size classification for harvesting intervals of 5, 10, and 20 years.

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Furniture Rough Mill Costs Evaluated by Computer Simulation

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Abstract

A crosscut-first furniture rough mill was simulated to evaluate processing and raw material costs on an individual part basis. Distributions representing the real-world characteristics of lumber, equipment feed speeds, and processing requirements are programed into the simulation. Costs of parts from a specific cutting bill are given, and effects of lumber input costs are discussed. GASP IV (A Combined Continuous/Discrete FORTRAN-based Simulation Language) was used.

NOTE

The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program. For cost information, please write: Northeastern Forest Experiment Station, Forestry Sciences Laboratory, P.O. Box 152, Princeton, West Virginia 24740.

Introduction

Traditional cost accounting methods are inadequate for comparing different production sequences. Traditionally, costs are evaluated in a furniture rough mill by product line or production run. For example, a quantity of lumber is fed into the rough mill in a day's production run. This lumber is converted into rough cut-to-size parts. The cost of this conversion is usually calculated by adding the cost of the lumber to the costs associated with the overall operation of the rough mill, such as wages, utility costs, and some percentage of the plant overhead. In this way, a gross estimate of the part costs is obtained by dividing the total costs by the quantity of parts produced. This method is sufficient for cost accounting purposes, however, it does not provide the accurate individual part costing that is necessary to compare different production sequences.

To compare one sequence with another, costs per part are needed. Production costs of individual parts enable rough mill designers and users to compare various types of rough mill configurations. Determining these costs can present very complex problems, especially where random events or elements have important effects on production. Converting rough lumber into furniture parts by crosscutting first is a case in point. Because of the random occurrence of defects in rough lumber, it is usually not possible to predict exactly how much time it will take to complete each step in the manufacturing process. Other elements also make it difficult to predict processing time and cost: the desired output will change from order to order, workers do not always work at the same speed, the capabilities of various machines differ, production rules can have unexpected effects on output, and different grades of lumber will also affect output.

The production costs in a crosscut-first furniture rough mill can be analyzed by computer simulation. The technique is a radical departure from the traditional cost control methods in the furniture industry. By using the computer to simulate the production sequences, we can measure part costs and, in particular, determine the value of each part as it passes through the rough mill.

The Problem

Determining actual costs of production for individual furniture parts presents a three-part task: First, develop the model of an existing rough mill to include all operations from the lumber breakdown hoist through the crosscut saws to the final machining-to-width on ripsaws; second, identify and measure important parameters within the rough mill that affect the cost of the furniture part being produced; third, establish the incremental cost of processing individual parts at each step in the production sequence.

Our approach to this task is to consider each part separately and assign costs on the basis of the amount of processing it actually receives. The cost of each step in the production sequence is a factor in a furniture part's cost only if the part receives processing at that step. By accumulating the processing received and the associated costs at each step in the production process, a cost for each finished part can be accurately determined.

Rough Mill Model

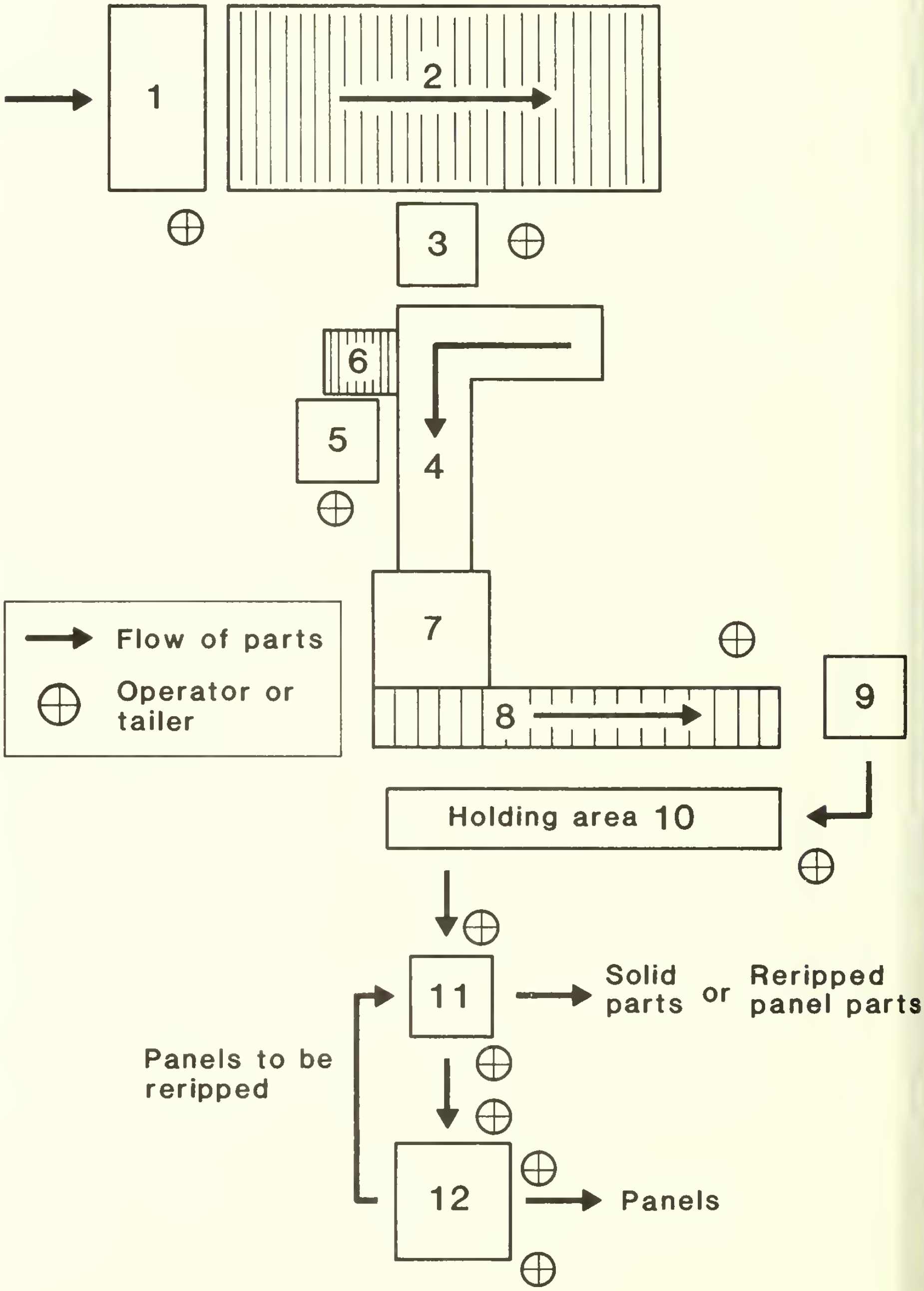
Evaluating production sequences in an existing rough mill has several advantages. Production figures from the existing mill provide benchmarks for evaluating the simulated production performance. Production parameters such as machine capability, feed speeds, sawing rates, and personnel availability are well established in an existing mill. Simulation involves describing the mill in a mathematical model that incorporates the production parameters and manipulating this model experimentally.

The model includes all production steps in an operating furniture rough mill. However, not every part goes through every production step. For example, only those parts containing visible defects such as knots, wane, or excessive cup go through the defect ripsaw. Other parts that contain no defects skip this processing step and do not incur any of its cost. These are important factors that affect the costs of production and must be accounted for.

Our crosscut-first furniture rough mill uses the following sequence of operations (Fig. 1): (The number in parentheses refers to the machine associated with each production step.)

- Lumber infeed—Rough, kiln-dried, graded lumber in random widths and in random lengths up to 16 feet starts into the mill on a tilted breakdown hoist (1).
- Conveyor—The lumber is unstacked one layer at a time onto a cross conveyor (2).
- Crosscut saws—Worker removes board from cross conveyor, inspects it to determine optimal parts lengths based on the current cutting bill in front of him, makes a trim cut on the leading edge of the board, and makes necessary cuts to produce cut-to-length random-width parts on the crosscut saw (3).
- Conveyor—As the parts are crosscut, they drop onto a conveyor (4) that takes them past the defect ripsaw to the planer.
- Defect ripsaw—Worker inspects each part, removes parts that have defects that can be removed by ripping, feeds ripsaw (5), and alines all other parts on the planer infeed belt.

Figure 1.—Flow chart of operations in a crosscut-first furniture rough mill.



- Offbearer conveyor—Automatically tailing ripsaw, the conveyor (6) returns parts to planer infeed belt.

- Planer—The planer or facer and planer (7) skip planes the boards on both sides to a standard thickness.

- Conveyor—From the tail of the planer, the parts move up a conveyor (8) to the sorting station.

- Sorting station—Worker removes parts from conveyor and stacks them on pallets by length at the sorting station (9).

- Holding area—After parts are sorted onto pallets according to length, they are placed in a holding area (10) until the rough mill foreman schedules their entry into the next processing step. Wages of the worker who handles pallets between sort and rip operations are divided between these two processing steps.

- Ripsaw—Worker feeds the random-width parts one at a time into the straight line ripsaw (11). One of these four multiple processing operations is performed:

  - Rip to remove defects, followed by rip to specific width for part with a finished width less than or equal to some minimum width

  - Rip to remove defects, followed by rip to produce glue line edge on both sides of random-width parts scheduled for gluing

  - Panel matching and/or sizing by laying up panels from random-width parts and ripping panel to specific width

  - Rip glued-up panels back to some specified width part.

- Offbearer station—Worker tails the ripsaw, moves edgings out of the way, and stacks the cut-to-length and width parts on pallets for further processing. Because the ripsaws perform up to four different types of processing, the next step in the production sequence depends on the type of processing being performed.

- Materials handler—Worker moves parts pallets from ripsaw area either to panel gluing area or to further processing beyond the scope of the rough mill model.

- Panel gluing infeed—Worker inspects parts, loads parts over glue applicator, alines parts in bed of panel gluing machine (12), and activates gluing machine.

- Panel gluing offbearer—Worker removes panels from gluing machine and stacks them on pallets.

- Materials handler—Worker moves parts on pallets from panel gluing operation to ripsaw or on to further processing beyond the scope of the rough mill model.

Parts that leave the ripsaw or panel gluing operation for further processing in the furniture mill have been cut to final rough part size; that is, to some specified length and width. All major defects have been removed and those defects that remain fall within the limits allowable for each part grade.

Rough Mill Simulation

In determining part costs, an accurate description of the mechanics of production is only one part of the solution. Everything else that affects the way the mill is operated must also be considered. These items are the inputs to the computer program, and how adequately they are identified and defined directly affects the value of our results. As a minimum, we have identified the following as critical inputs: cutting orders, raw material characteristics for various grades of lumber, instructions for operating the system, cost information including lumber costs, and wages of production personnel. These are the parameters that directly affect the production cost of furniture parts.

Cutting Orders

A cutting order, as opposed to a cutting bill, is the complete list of parts that a furniture manufacturer wants from a particular production run. Thus, while a crosscut saw operator is working to fulfill a cutting bill of up to 10 length-width combinations, that cutting bill is a part of a larger cutting order.

A typical furniture rough mill may process up to 200 part sizes in a single cutting order. The cutting order used here has 90 individual part lengths with 145 total length-width combinations for the finished rough part sizes for a variety of furniture items including chairs, tables, and cabinets. Input from the cutting order includes the length, width, thickness, and number of board feet for each part size.

The cutting order calls for 90 different lengths to be crosscut. Machine operators can handle no more than 10 at one time (the computer allows any number up to 10 to be used, although many mills would use fewer than 10). How are the lengths chosen? There are two criteria: priority value and absolute difference in length.

Priority value. Because any one of 10 lengths can be crosscut at any given time, a priority value is assigned by the furniture manufacturer's production scheduling division to each part size. This value determines when the part will be listed as one of the 10 "active" lengths. As the volume requirement for a particular part is satisfied, that part is replaced on the active cutting bill by the next part length in priority order until the requirements for all part sizes have been satisfied.

Absolute difference in length. This criterion is used in combination with priority ordering of parts to determine the entry of lengths on the cutting bill. The absolute difference between a length entering and any length already being cut must be at least 2 inches. This 2-inch difference was needed to enable crosscut saw operators and sorting personnel to differentiate one part size from another quickly. This restriction would be unnecessary in a rough mill where parts are sorted by an optical scanner or mechanical sorter. Also, the practical lower limit for crosscut saw operators may be the width between stops, about 1/2 inch, which is considerably less than the 2-inch restriction required in this model. Regardless of the size difference chosen, the restriction is a necessary production parameter.

Table 1 illustrates the information in the simulation input instructions for the 10 lengths with the highest priority in the cutting order. While Table 1 does not show all of the part lengths in the cutting order, it does show the longest and shortest lengths in the particular cutting order used. All of the other 80 part lengths fall within the range 76.75 to 14.5 inches. The 10 part lengths in Table 1 make up the cutting bill given to the crosscut saw operators at the start of the production run.

Raw Material Characteristics

A description of the lumber and estimates of the part yield after each step in the manufacturing sequence are needed as input to the simulation program. This information was obtained by on-site study at an existing crosscut-first rough mill. From observations at this rough mill and from yield studies available at the Forestry Sciences Laboratory in Princeton, West Virginia, I compiled the following types of lumber input information to describe the lumber entering the system and to calculate the amount of material left after each operation:

- Statistics describing the normally distributed lengths and widths of Selects and No. 1 and 2 Common grades of red oak lumber (Table 2)

Table 1. Typical cutting bill—first 10 lengths in the partial cutting order listed by priority

Priority	Length	Volume required
	Inches	*Board feet*
1 (lowest)	14.500	4,482
2	35.625	2,059
3	41.000	8,863
4	43.000	4,910
5	43.875	1,492
6	48.250	1,703
7	49.875	926
8	53.250	4,307
9	68.750	1,118
10 (highest)	76.750	550

Table 2. Parameters used to describe distributions of board sizes by grade (parameters in inches)[a]

Grade	Mean	Minimum	Maximum	Standard deviation
		LENGTH		
Select	192	72	200	44.66
1 Common	144	48	200	44.66
2 Common	118	47	200	44.66
		WIDTH		
Select	5.35	4	11	1.31
1 Common	5.31	3	8	1.26
2 Common	5.31	3	8	1.26

[a] Based on a sample of boards entering existing rough mill at breakdown hoist. These values are input as variables in model and can be altered to meet user's needs.

Table 3. Distribution of crosscuts made versus number of parts produced

Number of crosscuts made	Number of parts produced per board						
	1	2	3	4	5	6	8
3	0.25[a]	0.75	—	—	—	—	—
4	—	0.28	0.72	—	—	—	—
5	—	0.08	0.48	0.44	—	—	—
6	—	0.07	0.22	0.64	0.07	—	—
7	—	—	0.29	0.14	0.43	0.14	—
8	—	—	0.10	0.50	0.20	0.20	—
9	—	—	—	—	—	0.33	0.67

[a] Interpreted as follows: 25 percent of the time when three crosscuts are made on a board, only one part is produced out of that board.

- Parameters describing the normally distributed board thickness, in inches, for 4/4-inch-thick lumber entering the rough mill. These are:

Mean	Minimum	Maximum	Standard deviation
1.088	0.835	1.440	0.123

- Frequency distribution of crosscuts made in comparison with the number of parts produced from each board (Table 3)
- Frequency of parts processed at defecting ripsaw (Table 4).

Table 4. Frequency of processing alternatives at defecting ripsaw

Percent of boards arriving at ripsaw	Action taken
30	Bypass defect ripsaw
50	Split to remove cup
20	Defect ripped out
100	

Equipment Operating Instructions

Operating instructions and information needed to regulate the simulation program include equipment speeds, belt speeds, travel distances, processing rates for each piece of equipment, and time delays for setting up machinery between cutting bills. The information on processing rates for ripsaws and gluing machines and the time delays are built into the model; the other machine characteristics for conveyors, crosscut and defect ripsaws, and planers are input as variables each time the program is run. These variable operating instructions are summarized in Table 5.

Table 5. Machine characteristics used as variable input[a]

Equipment or operation	Length	Rate or time	Comments
	Feet		
Breakdown hoist			Release rate controlled by operator
Cross conveyor	77	25.00	Feet per minute
Crosscut saw	8	6.25	Board feet per minute
Conveyor times to defecting ripsaw:			Expressed in minutes
from saw 1		0.40	
saw 2		0.72	
saw 3		1.04	
saw 4		1.26	
saw 5		0.74	
saw 6		0.95	
saw 7		1.15	
saw 8		1.36	
Defecting ripsaw	6	130.00	Feet per minute
Offbearer conveyor	5	70.00	Feet per minute
Conveyor time to planer from ripsaw:		0.40	Minutes
Planer	8	90.00	Feet per minute
Conveyor time to sort from planer:		0.4	Minutes

[a] These values reflect the characteristics of the existing mill used as an example. Minor changes to the program can be made for different layouts and equipment by altering these variables.

Rough mill processing begins when lumber is moved from the breakdown hoist to the cross-conveyor. This operation is handled by the first crosscut saw operator and is scheduled whenever the cross-conveyor becomes less than 50 percent full. The operator then moves lumber onto the conveyor until it is over 95 percent full; that is, the entire length of the conveyor is covered with boards, single thickness, lying side-by-side for at least 95 percent of its overall length. The 50 and 95 percent figures are used to determine when lumber is off-loaded, both in the actual mill and in the simulation program.

The crosscut saw operators pull boards off the cross-conveyor and cut parts to length at the specified processing rate. The program is flexible: up to eight crosscut saws may be operating at the same time.

In the simulated mill, the material from four of the crosscut saws is conveyed past a defecting ripsaw to a skip-planer. The material from the other four crosscut saws is conveyed separately to another defecting ripsaw and planer. The feed speeds for the belt conveyors are different for these two lines, but the processing rates for ripsaws and planers are the same. The belt conveyor tailing both planers goes directly to the sorting station.

Production Cost Information

In addition to the physical characteristics of lumber input and the equipment operating instructions, two types of costs are defined as input to the simulation program. These are the cost of lumber input to the mill and the cost of labor involved with equipment operation.

It is important to note that this is a study of production costs and not of prices. The price of a part will include such items as factory overhead, selling costs, administrative costs, general expenses, and profit. These are not included in the calculation of production costs. Our primary concern was to allocate direct labor and lumber costs to the individual parts as they pass through the various manufacturing steps.

Lumber costs contain two components: purchase price and cost of handling. Purchase price will, of course, vary with grade and species. The cost of handling is a fixed cost per board foot that estimates the cost of regrading, stacking, drying, and handling before entry into the rough mill. The actual rough mill simulated uses a prior handling cost of $43 per M bm (thousand board feet).

Rough mill labor costs, based on machining time, are assigned to individual parts. If it takes twice as much ripping and crosscutting time to produce a part, that part is assigned twice as much labor costs. These costs include an hourly wage cost, an estimate of fringe benefit costs (expressed as a percentage of the hourly wage) and any applicable bonus for incentive work. All of these costs are combined for each operation and may therefore reflect the cost of more than one worker. In fact, the labor costs for the material handlers described in the model are divided between the sorting and ripsaw stations. The labor costs for the individual machining operations shown in Table 6 represent 1980 practice.

Table 6. Combined labor costs, by type of operation

Operation	Rate[a]	Comments
	$/hour	
Breakdown hoist	5.30	
Cutoff saw	5.64	
Defect ripsaw	5.35	
Sort	5.21	Includes materials handler
Ripsaw	14.06	Includes materials handler and offbearer
Gluing	27.81	Includes materials handler and operators

[a] Includes hourly wage cost, estimated fringe benefit cost, and (for ripsaw and gluing) an estimate of bonus for incentive work.

Table 7. Average cost of processing, by type of process

Process	$/part	$/bd ft
Breakdown hoist	0.011	0.002
Cutoff saw	0.023	0.022
Defecting ripsaw	0.009	0.016
Sort	0.028	0.041
Rip—solid parts	0.020	0.072
Rip—glue line edge	0.087	0.110
Rip—panel matching/sizing	0.108	0.030
Rip—panels to parts	0.018	0.056
Gluing panels	0.162	0.044

The Output

Our computer simulation results are processing costs, production cost of parts, and yields of parts as they flow through the system. We can determine the cost of each individual part and then group these parts in any way desired. Results can be determined as a function of part length, part width, part quality, or any combination. It is most useful to sum up the data in terms of part length because part length is related to part cost.

Any change in rough mill design or inputs will show clearly in these costs. Although, for simplicity, we talk in terms of averages, it is important to remember that these results are from individual part costs and are not the same as numbers calculated by dividing total plant costs by total number of parts produced.

Processing Costs

Processing costs are determined at each point where there is labor or material input. Starting with the breakdown hoist and ending with the final rip-to-size, the cost of each processing step on the individual parts is calculated. These costs are summarized in Table 7.

Parts that are the same size and that require the same machining operations have the same processing costs. It is important to note that the cost of an individual processing step such as one rip or one crosscut is directly related to machine or processing time and is a function of part length or width. Thus, if a part requires one rip and one crosscut, the processing cost is the same whether the lumber input is FAS (First and Seconds) or 2 Common. On the average it will take more operations to process the lower grades because of the need to remove or work around more defects. But the price differential among grades is such that using the lower grades may be cost effective.

Processing cost at the breakdown hoist is a function of the wage of the operator and the speed of the lumber conveyor. This is the only exception to the rule that processing costs are similar for all grades of lumber input. On the average, it costs about one cent to offload a board from the breakdown hoist onto the cross conveyor. This cost per board is the same regardless of the grade of lumber, but better grade boards contain more board feet of usable lumber. The processing cost of this operation, per board foot of lumber input, is obtained by dividing the constant cost per board by the board foot volume of the piece being processed. The average board foot volume per board for the three grades of lumber input is as follows:

Grade	*Average volume/ board input*
Select	7.317 board feet
1 Common	5.678 board feet
2 Common	4.752 board feet

Thus, for 2 Common grade lumber, the average cost of the breakdown operation is $0.0024 per board foot; for 1 Common grade lumber it is $0.0020; and for Select grade lumber, $0.0015.

Cost of Processing Parts—Through Sort Operation

After the cost of each processing step has been determined, the cost of processing an individual part

Table 8. Average cost of processing, by part length, through the sort operation for random-width parts

Part length	$/part	$/bd ft	Part length	$/part	$/bd ft
Inches			*Inches*		
14.500	0.134	0.145	25.875	0.094	0.102
14.624	0.131	0.142	26.750	0.095	0.104
15.125	0.128	0.139	27.000	0.094	0.104
15.250	0.125	0.135	29.000	0.087	0.096
15.375	0.125	0.135	29.875	0.089	0.097
15.500	0.124	0.135	30.000	0.089	0.098
15.625	0.125	0.135	31.000	0.087	0.097
15.750	0.122	0.133	31.250	0.087	0.094
16.000	0.124	0.133	31.375	0.085	0.093
16.250	0.122	0.132	32.000	0.085	0.093
16.365	0.125	0.133	32.500	0.084	0.093
16.750	0.117	0.128	33.000	0.082	0.090
16.875	0.122	0.132	33.125	0.086	0.095
17.000	0.125	0.134	33.750	0.083	0.092
17.125	0.124	0.135	34.375	0.084	0.092
17.500	0.117	0.127	35.000	0.080	0.089
17.625	0.115	0.125	35.625	0.085	0.095
17.750	0.116	0.126	36.375	0.080	0.088
17.875	0.118	0.129	36.500	0.079	0.088
18.000	0.111	0.123	36.750	0.083	0.091
18.500	0.115	0.125	36.875	0.078	0.087
18.750	0.111	0.123	38.375	0.083	0.091
18.875	0.111	0.122	39.250	0.075	0.085
19.000	0.110	0.119	39.875	0.076	0.083
19.125	0.110	0.118	40.500	0.075	0.083
19.375	0.110	0.119	41.000	0.077	0.085
19.500	0.112	0.122	42.500	0.077	0.085
19.625	0.110	0.121	43.000	0.077	0.085
19.875	0.105	0.120	43.375	0.075	0.082
20.000	0.112	0.123	43.875	0.078	0.087
20.750	0.098	0.110	44.375	0.077	0.081
21.250	0.105	0.113	44.625	0.073	0.080
22.000	0.103	0.113	44.750	0.071	0.080
22.375	0.108	0.116	48.250	0.075	0.083
22.625	0.099	0.108	49.250	0.070	0.079
22.750	0.106	0.117	49.500	0.073	0.080
23.000	0.100	0.109	49.875	0.076	0.084
23.500	0.100	0.110	51.000	0.076	0.083
24.000	0.095	0.105	51.250	0.071	0.079
24.125	0.094	0.102	53.000	0.070	0.078
24.500	0.099	0.108	53.250	0.071	0.080
24.750	0.099	0.109	55.500	0.069	0.078
24.875	0.096	0.106	59.000	0.070	0.078
25.000	0.093	0.102	68.750	0.066	0.075
25.750	0.095	0.105	76.750	0.064	0.072

can be found by summing the costs of all processing steps it goes through. Recall that the typical rough mill processes parts in two stages: up through the sort operation, and then all subsequent operations. In the first stage, the width of each part depends on the width of the board from which it was cut. However, the length of the part is fixed once it has passed the crosscut step. To summarize the cost of parts at the end of the first stage, the processing costs for parts of each length were collected and averaged. The cutting order used in the simulation contained 90 different part lengths. Excluding the value of raw material input, the typical costs of processing these 90 lengths through the sort operation are shown in Table 8.

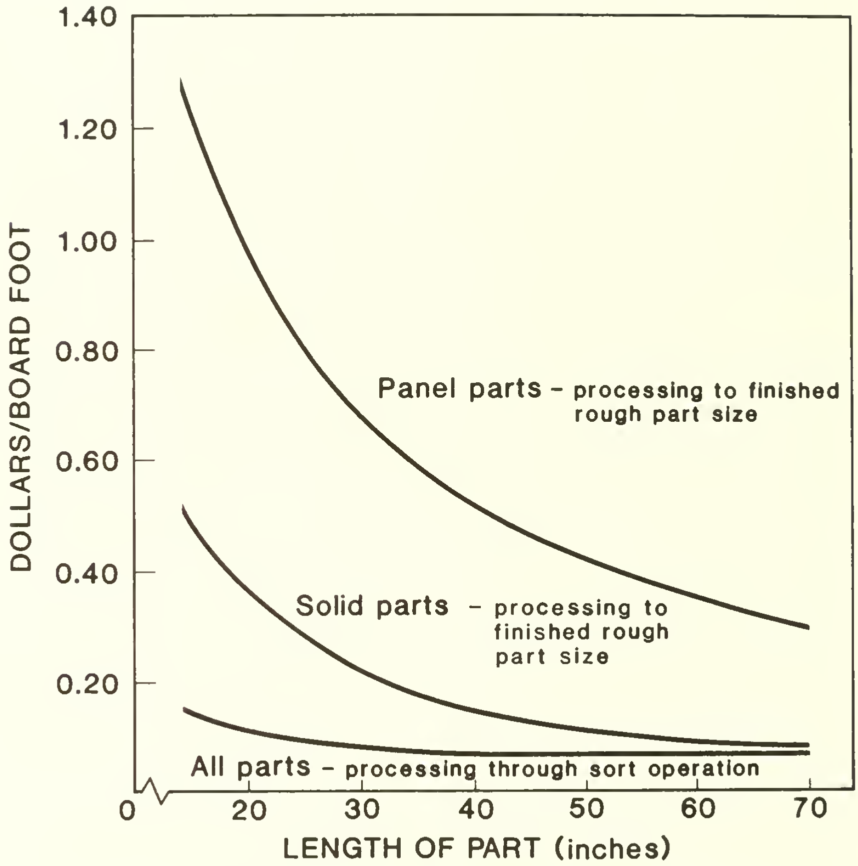
The cost per board foot for processing parts through the sort operation is inversely related to the length of the part. This appears unreasonable at first, but a 14-inch part contains only one-half the board foot volume of a 28-inch part if both are the same width. So, it must take more processing to obtain the same volume of 14-inch parts as 28-inch parts.

Figure 2 illustrates the relationship between the cost per board foot and the length of the part in inches. Regression analysis of the costs per board foot shown in Table 8 defines the relationship between cost (Y) and length of part (x) as follows:

$$Y = 0.0551 + 1.2691 \left(\frac{1}{x}\right)$$
$$R^2 = 0.98$$

Over the range of part lengths tested in this study, the part processing costs per board foot are estimable within very close tolerances. The standard deviation resulting from the regression analysis is 0.0024, or less than three-tenths of a cent per board foot.

Figure 2.—Processing costs in relation to length of part.



Cost of Processing Parts—From Sort to Finished Rough Part Size

In the second stage of the typical rough mill, parts are cut to specific lengths and widths. Part costs in this stage may be separated into three distinct groups: solid, glued-up panel, and reripped panel parts. The cutting order used in the simulation of the rough mill contains a total of 145 different length and width combinations. Twenty-eight of these are solid parts; 114 are panel parts. Typical costs per board foot for processing these parts are shown in Tables 9 and 10. These represent the average costs for parts of a particular length and width within the specified group.

The remaining group is reripped panel parts. These receive the most processing and consequently have the highest processing cost. Two of the three reripped parts are the same length, 14.5 inches; the third part is 15.125 inches in length. The average cost per board foot for processing these 4/4-inch-thick parts is as follows:

Length (in)	*Width (in)*	*Cost ($/bd ft)*
14.5	2.6875	1.66
14.5	3.000	1.58
15.125	3.000	1.65

Costs per board foot through the second stage of the rough mill are also inversely related to the length of the part, as shown in Figure 2. Equations relating the cost per board foot (Y) to the length of the part (x) in inches are as follows: for solid parts, $Y = -0.0481 + 8.2014 \left(\frac{1}{x}\right)$ $R^2 = 0.97$; for panel parts, $Y = 0.0454 + 18.6648 \left(\frac{1}{x}\right)$ $R^2 = 0.98$. The standard deviation of the estimated cost per board foot for solid parts is 0.03; for panel parts it is 0.05. These equations may be used to predict the processing cost of finished rough parts between 14.5 and 76.75 inches in length.

The difference between the processing costs of solid and panel parts is the result of additional processing required to produce a finished-to-size panel part. However, when the costs are separated by degree of processing, the relationship between cost per board foot and part length is consistent and estimable within close tolerances for both solid and panel parts. The cutting order did not contain enough different reripped panel part lengths for a regression analysis based on part length. However, the same relationship between cost per board foot and part length would be expected for these parts.

Table 9. Average processing costs for 4/4-inch thick solid parts, by length

Length	Width	Cost
- - - - - Inches	*- - - - -*	*$/bd ft*
14.500	1.0000	0.59
14.500	0.1250	0.51
14.500	1.3750	0.55
14.500	1.7500	0.51
14.500	1.1875	0.55
14.500	2.0000	0.52
14.500	2.3750	0.51
14.625	2.6250	0.50
15.250	2.6250	0.46
15.375	2.5000	0.48
16.000	2.8750	0.44
16.250	2.5000	0.43
17.125	1.7500	0.43
19.375	0.5625	0.44
19.625	2.3750	0.33
22.375	1.7500	0.29
22.750	2.0000	0.30
23.500	2.2500	0.28
24.125	1.1250	0.27
32.500	2.0000	0.19
32.500	2.2500	0.20
36.500	2.2500	0.15
36.750	2.5000	0.17
44.625	2.2500	0.14
49.250	2.1250	0.13
49.500	2.5000	0.13
51.000	2.2500	0.14
68.750	2.3750	0.10

Table 10. Average processing costs for 4/4-inch-thick panel parts, by length

Length	Width	Cost	Length	Width	Cost
- - - - - Inches	*- - - - -*	*$/bd ft*	*- - - - - Inches*	*- - - - -*	*$/bd ft*
14.500	17.4375	1.41	24.813	14.5625	0.81
14.500	19.1250	1.29	24.875	23.3125	0.70
14.500	20.7500	1.29	25.000	14.6250	0.84
14.500	21.1250	1.19	25.750	16.7500	0.80
14.500	22.0000	1.33	25.750	21.5625	0.75
14.500	22.1250	1.32	25.875	24.3125	0.82
14.500	22.1250	1.48	26.750	17.7500	0.73
14.500	23.2500	1.38	27.000	20.9375	0.72
14.500	23.3125	1.42	29.000	15.0000	0.67
14.500	23.4375	1.30	29.000	22.1250	0.66
14.500	23.5625	1.38	29.875	22.1250	0.63
14.500	23.6250	1.30	29.875	23.4375	0.65
14.500	24.0000	1.32	30.000	25.5000	0.65
14.500	24.2500	1.36	30.000	25.7500	0.65
14.500	24.3125	1.40	31.000	21.9375	0.62
15.375	19.8750	1.27	31.250	22.0000	0.64
15.500	20.1250	1.27	31.375	17.0625	0.65
15.625	24.3125	1.22	31.375	22.0000	0.62
15.750	22.1250	1.31	32.000	21.5625	0.61
16.250	20.4375	1.13	32.500	23.3125	0.67
16.250	23.1875	1.17	33.000	23.3125	0.57
16.375	22.1250	1.34	33.125	17.5000	0.60
16.750	19.5625	1.14	33.750	21.9375	0.60
16.750	24.1875	1.11	34.375	17.0625	0.56
16.875	17.6250	1.19	35.000	23.3125	0.56
17.000	23.8750	1.12	35.625	16.2500	0.61
17.500	24.3125	1.06	35.625	19.0000	0.57
17.625	21.7500	1.07	36.375	16.7500	0.56
17.750	23.3125	1.07	36.750	16.8750	0.56
17.875	19.5625	1.09	36.875	20.7500	0.49
18.000	23.3125	1.11	38.375	16.7500	0.53
18.500	20.7500	1.11	39.250	23.4375	0.54
18.750	22.1250	0.99	39.875	24.3125	0.51
18.875	18.7500	1.07	40.500	21.5625	0.54
18.875	20.2500	1.06	40.500	22.0000	0.47
18.875	20.3125	0.98	40.500	23.6250	0.47
18.875	21.0625	1.02	41.000	15.5000	0.49
19.000	21.6875	1.04	41.000	20.1250	0.50
19.125	24.3125	0.99	41.000	31.0000	0.50
19.375	24.4375	1.03	42.500	14.0000	0.51
19.500	16.8750	0.99	43.000	21.3750	0.49
19.625	22.6250	1.04	43.000	27.7500	0.48
19.875	22.1250	0.94	43.375	14.8750	0.50
20.000	13.1250	1.03	43.875	15.3750	0.51
20.750	23.3125	0.79	43.875	21.9375	0.46
21.250	18.0000	0.93	44.375	22.1250	0.46
22.000	18.4375	0.88	44.750	16.2500	0.48
22.000	20.4375	0.85	48.250	13.5000	0.47
22.000	21.5625	0.92	49.500	20.1250	0.45
22.000	23.3125	0.84	49.875	13.5000	0.44
22.000	24.1875	0.85	51.250	14.1250	0.45
22.625	21.1875	0.77	53.000	17.5000	0.40
23.000	13.3750	0.92	53.250	17.7500	0.44
23.500	21.9375	0.76	55.500	24.1875	0.41
23.500	22.1250	0.81	59.000	21.5625	0.39
24.000	13.5000	0.92	76.750	22.1250	0.29
24.500	17.8125	0.84	76.750	22.9375	0.31

Part Yields and Final Production Costs

Along with processing costs, part yields are included in the final output from simulation of a typical rough mill. Part yields provide the needed measure of the cost of material lost in processing. As noted earlier, the production cost of an individual part is made up of processing costs, which account for the direct labor involved, and material costs. However, the cost of material lost in production must be considered when production costs are calculated, in addition to the cost of material left in the part.

Part yields are used to adjust the cost of material in a part to reflect the allocation of costs of material lost in processing. For example, if the value of lumber input is $200 per M bm and the final yield of the furniture parts is 48 percent, then the material cost for 480 board feet of parts produced from 1 M bm of lumber is $200. The material cost per board foot is obtained by dividing the cost of lumber input by the board feet of parts, or in this example, $200 ÷ 480 = $0.42 per board foot.

Part yields differ slightly depending on the type of processing received in the rough mill:

Type of processing	*Average yield (in percent) from 2 Common lumber*
Solid parts	44
Panel parts	49
Reripped panel parts	48

Thus, solid part material costs are higher and panel part material costs are slightly lower than the material cost for reripped panel parts. Again, using the value of $200 per M bm for lumber input, solid part material costs would be $0.45 per board foot while panel part material costs would be $0.41 per board foot.

Finally, the dollar cost per board foot for processing is added to the material cost per board foot to get the total production cost for each part. For example, a 14.5- by 1.0-inch solid part has an average processing cost per board foot of $0.59. If the lumber used for cutting this part is valued at $200 per M bm or $0.45 per board foot after adjusting for part yield, the cost of producing this part would be $0.59 + $0.45 or $1.04 per board foot.

Summary

The production sequence in a conventional crosscut-first rough mill is reproduced by computer simulation and tested against a well-run conventional rough mill. Benchmark costs of rough mill processing are established for the typical mill. Overall part production costs are obtained by combining material and processing costs. The program used can easily be modified through changes in input variables and minor internal changes to reflect the operating characteristics of any conventional crosscut-first rough mill.

Processing costs are a function of time in the machine; given an operating rate for a processing step, the amount of time that a part spends in the step can be determined. This time depends on the size of the part.

At the ripsaw four operations are possible. The operating rates differ for each of the four, so four separate processing costs must be considered at this step.

Processing costs are independent of grade of lumber input: the same time is required to rip a part of a given length from a Select grade board as from a 2 Common grade board. Parts that are the same size and require the same machining operations have the same processing costs, regardless of the grade of lumber they are made from.

Processing costs per board foot is inversely related to part length because a short part contains less volume than a long part. Thus, more processing of short parts is required to produce the same total volume as a long part.

Overall part production costs, combining material costs with processing costs, can be calculated using the part yields in the model to allocate the cost of material lost in processing. These costs are not the final selling or transfer price of parts; rather, they are costs of a specific production process and are intended for use in making comparisons with cost of parts from other processes.

This study was the first step in developing the methodology for determining production costs on an individual part basis. We have an accurate model. The next step is to develop a general model that will make comparisons with any mill design.

Anderson, R. Bruce. **Furniture rough mill costs evaluated by computer simulation.** Res. Pap. NE-518. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 11 p.

A crosscut-first furniture rough mill was simulated to evaluate processing and raw material costs on an individual part basis. Distributions representing the real-world characteristics of lumber, equipment feed speeds, and processing requirements are programed into the simulation. Costs of parts from a specific cutting bill are given, and effects of lumber input costs are discussed. GASP IV (A Combined Continuous/Discrete FORTRAN-based Simulation Language) was used.

ODC 836.1; 796.1

Keywords: Processing costs; computer program; FORTRAN: GASP IV; rough flat dimension

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New Turf for Gypsy Moth; There's More at Risk Downrange

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Abstract

Data collected from 600 field plots in central Pennsylvania forests threatened by gypsy moth point to a greater potential for damage downrange. Though greater than in the Poconos, losses are not expected to be spectacular. Still, some forest landowners will suffer heavy tree mortality to the pest.

Most of the recent furor over gypsy moth has not been about what it has done to the forest resource but rather about the nuisance created by caterpillars around home and recreation sites. Control efforts have been concentrated in residential areas and parks; not in the woods. Forest stand losses to gypsy moth during the past decade have reinforced the general lack of public concern over the impact of the insect on our woodlands. For example, a recent survey by the Pennsylvania Bureau of Forestry (Quimby 1981) showed that, in forest stands sustaining defoliation of 60 percent or more, cumulative tree mortality over a 10-year period averaged 20 percent. Losses in timber value averaged $16 per acre; less than $2 per acre per year. Our study in the Pocono Mountain Region of northeastern Pennsylvania yielded similar results (Gansner and Herrick 1979). Cumulative mortality (trees 3 inches in dbh and larger) associated with an outbreak in the Poconos during the early 70's averaged 13 percent over a 5-year period. Hardly a good thinning. Losses in timber value averaged $14 per acre; less than $3 per acre per year.[1] These are not the kind of impacts that inspire widespread, massive control efforts.

[1] Conversion standards developed by Mendel et al. (1976) were used to estimate timber value. These value standards account for current average regional conversion costs and incorporate species, dbh, butt log grade, and merchantable height for each tree. For example, a 16-inch diameter red oak having butt log grade 2 with merchantable height of two logs and containing 180 board feet (International 1/4-inch rule) was valued at $7.08.

This is not to say that defoliation has not taken its toll on the forest. No doubt, overall growth in timber volume and value would have been greater without gypsy moths. But, as the Pocono study showed, only a small percentage of infested stands suffer severe losses. Only 10 percent of the stands lost more than $30 per acre. Many of the trees that died were small and of low grade. Oak species were hit hard and their stocking is down, but species less vulnerable to gypsy moth such as red maple, hickory, black gum, ash, and yellow-poplar make up a greater proportion of average stocking now. Before infestation most stands were fully stocked or overstocked. They still are. Significant losses in timber volume and value occurred during the early years of infestation but most of them were offset by growth in later years. Most stands have more volume and value now than they had before infestation (Gansner and Herrick 1982). As Powell and Barnard (1982) put it, the gypsy moth's "impact on our future timber supplies has not yet been demonstrated to be of major consequence."

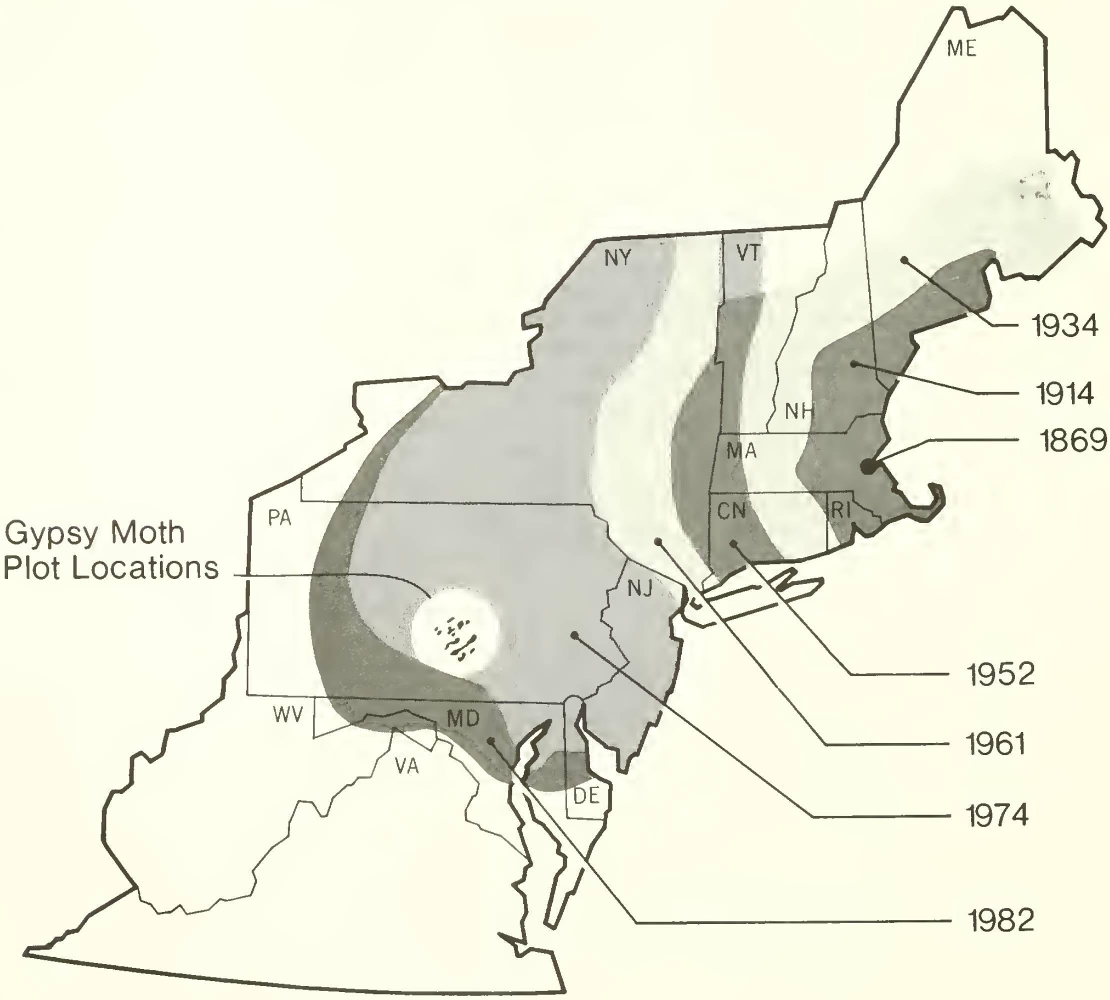
There is, however, growing concern among forest landowners and managers that things could become more serious as the outbreak spreads south and west into forests where oak stocking is greater and timber quality is better. What actually occurs downrange will depend on a number of interrelated factors such as the frequency and intensity of attack, the vulnerability of host trees, the effectiveness of control programs, and the influence of natural phenomena like predators and weather. And since these factors are difficult to predict, there's no way we can forecast impacts of the pest accurately.

In an attempt to measure impacts downrange, some 600 field plots have been installed in central Pennsylvania in advance of gypsy moth infestations. They are located between State College and Harrisburg in the heart of Pennsylvania's oak country (Fig. 1). Most of these plots were not significantly defoliated until 1981, so it's too early to report any definitive results. However, we can compare some key characteristics of stand condition for threatened field plots in central Pennsylvania with the preoutbreak status of infested plots in the Pocono Mountain region to get a relative indication of what to expect:

	CENTRAL PA		POCONOS	
	Mean	*Range*	*Mean*	*Range*
Percent of basal area in oak	68	0-100	56	0-100
Percent of basal area in trees with poor crowns[2]	11	0-89	8	0-69
Average dbh (inches)	7.4	3.8-13.4	7.0	4.7-10.8
Stand age (yr.)	72	15-175	68	25-105
Board foot volume per acre	5,500	0-28,200	4,100	0-23,100
Standing timber value per acre ($)	159	1-1,525	132	20-840

[2] Crowns were classed as poor when 50 percent or more of the branches were dead (allowances permitted for non-self-pruning species); when foliage density, size, or coloration was of subnormal quality; or when epicormic sprouting was heavy.

Figure 1. Spread of gypsy moth and location of central Pennsylvania plots.



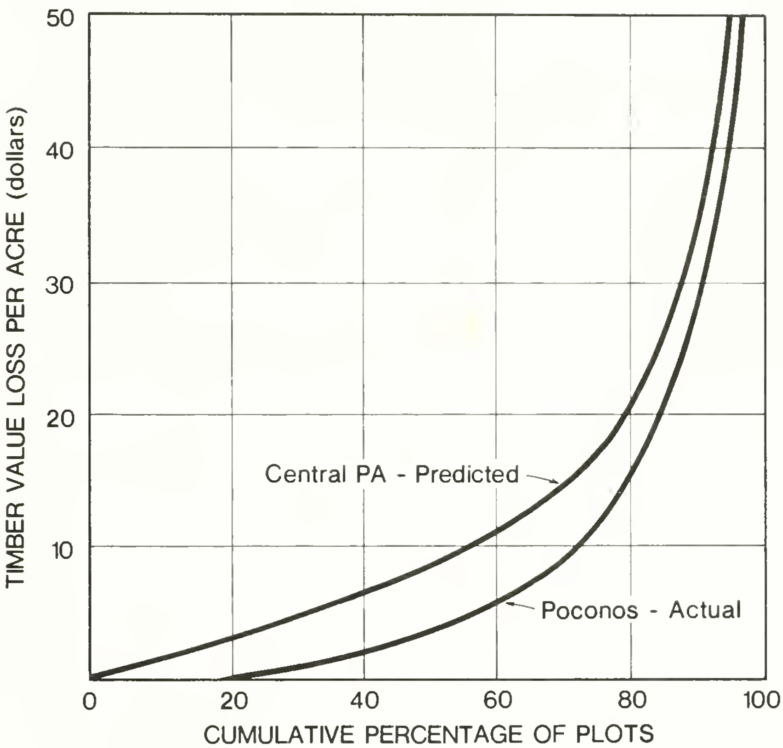
Oaks are a favorite food of the gypsy moth and there is more oak stocking downrange. On average, oaks account for 68 percent of the basal area in the central Pennsylvania plots. Oaks averaged only 56 percent of the basal area in the Pocono plots.

Tree vigor is a critical determinant of vulnerability to gypsy moth. Many trees that are old and in poor condition die after one heavy defoliation. Stand age and the proportion of stocking in trees with poor crowns are both greater in the central Pennsylvania plots than they were in the Pocono plots.

Timber is larger downrange. The average dbh of threatened stands in our central Pennsylvania study is 7.4 inches as opposed to 7.0 inches in the Poconos. Thirty percent of the central Pennsylvania stands average 8.0 inches dbh and larger. Only 18 percent of the Pocono stands were that big. There's more sawtimber volume downrange too, averaging 5,500 board feet per acre versus 4,100 board feet in the Poconos. And as you might expect, timber value is also greater. The value of standing timber in central Pennsylvania plots averages $159 per acre, 20 percent more than in the Poconos. What this all adds up to is a greater potential for economic loss downrange.

Techniques for predicting forest stand losses to gypsy moth that include the use of easy-to-measure key stand characteristics have been developed from the Pocono data and are now being tested and refined. Typical of the models coming out of this effort is

Figure 2.—Comparison of predicted value losses in central Pennsylvania with actual losses in the Poconos, 1972-1976.



an equation for estimating losses in timber value for defoliated forest stands:

$$PVL = 0.49 + 1.02(PPC) + 0.02(PWO)$$

where

PVL = Percentage of timber value that will be lost

PPC = Percentage of live basal area in trees with poor crowns

PWO = Percentage of live basal area in trees of the white oak species group.

Only two of the many elements of stand condition analyzed as predictor variables were significant; they are in this equation. Their inclusion makes especially good sense because (1) trees with *poor crowns* have lower vigor and are more likely to die after defoliation, and (2) *white oaks* are preferred food of gypsy moth and are usually attacked more severely than other tree species.

This equation was applied to the central Pennsylvania plots to estimate the potential hazard of impending gypsy moth attacks to timber value. Comparison of these value loss estimates with losses that actually occurred in the Poconos reinforces the inference that there is more at risk downrange (Fig. 2). The median loss for plots in the Poconos was $4 per acre; that is, half the plots lost at least this much value. The median loss predicted for central Pennsylvania is twice that. Over 40 percent of the central Pennsylvania plots are predicted to lose more than $10 per acre. Only 28 percent of the Pocono plots lost that much timber value.

Though losses are expected to be greater downrange, they aren't expected to be spectacular. Still, some forest landowners will suffer heavy tree mortality and will lose hundreds of dollars worth of timber to the pest (Fig. 3). These are the people that planners of cost-effective gypsy moth management programs have to be most concerned about. Operational decision-making guides must be able to help us determine not only how much forest land to protect but also which stands. Field plots installed in advance of gypsy moth outbreaks will be used to monitor impacts of the insect as it spreads to new frontiers of forest vegetation. They will also provide data needed to improve techniques for predicting and evaluating damages.

Figure 3.—Most of the timber value in this stand was lost to gypsy moth.

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System 6: Making Frame-Quality Blanks

from White Oak Thinnings

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Abstract

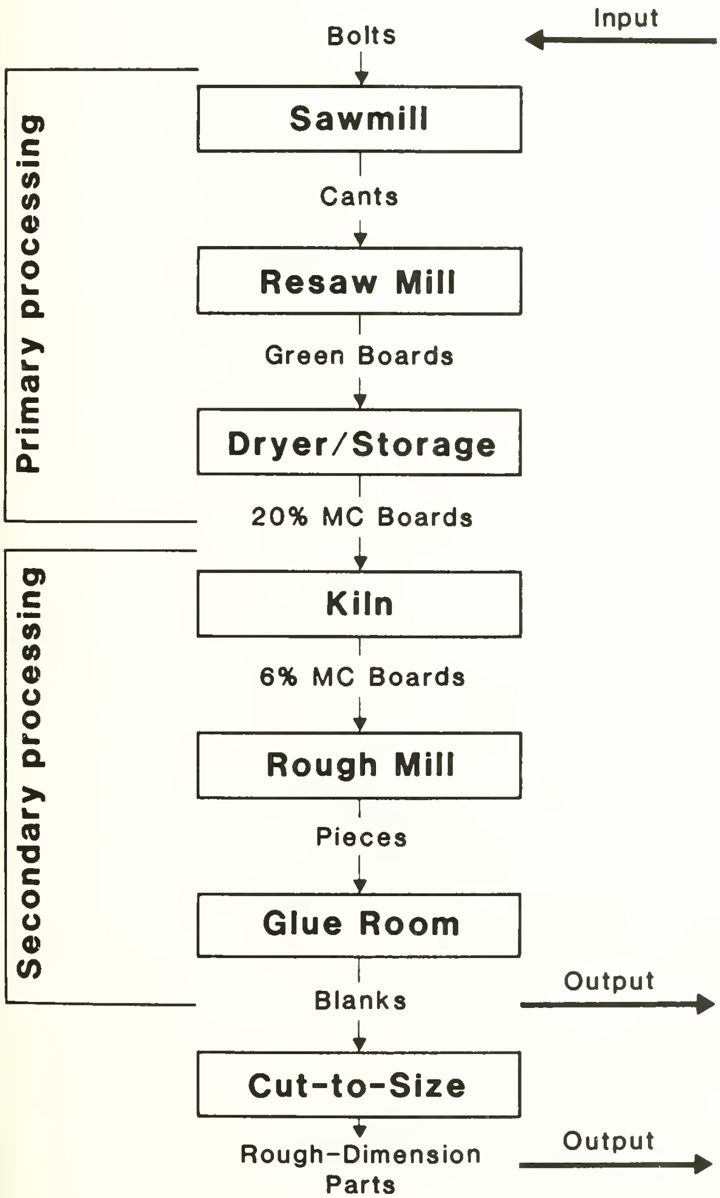
Low-grade white oak timber removed during a timber stand improvement cut on the Jefferson National Forest in Virginia was made into sawlogs, poles, 6-foot bolts, 4-foot bolts, pulpwood, and firewood. The 6-foot bolts were sawed to two cants per bolt; cants were resawed to 4/4 System 6 boards; boards were dried to 6 percent moisture content and made into frame blanks using System 6 technology. The blanks were used by an upholstered furniture company to make frames and were found to be very satisfactory. Yields of required frame blanks were good, 56 percent, when only the poorest two-thirds of all boards were used. The better boards can be used to make clear-quality blanks.

Introduction

In this paper we explain how we used System 6 processing technology with small-diameter, low-grade white oak timber to make standard-size blanks for frame parts. Upholstered furniture and recliner companies need strong, sound parts for the frames that will be covered with fabric. We made frame quality blanks in standard lengths, all 20 inches wide, and had a furniture company use these blanks to make their frame parts.

Using small-diameter, low-grade timber to make furniture-grade products with System 6 is new. The marketing differences between conventional hardwood methods and System 6 are explained in a research paper by Reynolds and Gatchell (1979). The System 6 technology is explained in a second paper by Reynolds and Gatchell (1982). The process is shown schematically in the Figure 1 flowchart. Standard-size blanks are explained in a research paper by Araman et al. (1982).

Figure 1.—System 6 process flowchart.



Frame Blanks

In a study made at the Forestry Sciences Laboratory, Princeton, West Virginia, to determine furniture parts requirements, requirements from 20 major furniture companies were divided into clear, core interior, and frame-quality classes (Araman et al. 1982). For each quality class, part size data were organized by thickness and length. In each thickness the least number of blank lengths were found that would yield all parts with no more than 10 percent end-trim loss. The resulting lengths and requirements for 4/4 frame-quality blanks are shown in Table 1.

Table 1. Standard-size 4/4 frame blank requirements (in square feet of blanks 20 inches wide)

Blank length	Quantity of blanks required[a]
Inches	*Square feet*
70	40
54	25
44	50
33	110
29	123
27	166
24	112
22	169
19[b]	83
17[b]	83
13[b]	39
Total	1000

[a] Data taken from Araman et al. 1982. We have assumed that 70 percent of the blanks are for upholstered furniture and 30 percent for recliner frames.

[b] Salvage length blanks: may be less than but no more than the requirement shown.

Frame quality material "may contain any defects that will not materially impair the strength of the individual piece for the use intended" (Hardwood Dimension Manufacturers Association 1961). This definition is too broad if blanks are to be purchased from many sources by many furniture and recliner companies, so we added the following quality specifications:

- No defects are permitted within 1 inch of either end.

- Defects within each piece making up the blank are limited to one-half the piece width with no more than one such defect per foot of piece length.

- Wane may not be on more than one edge, may not be more than one-half the piece thickness, and may not extend more than half the length of the piece.

- No shake or split longer than 1 inch will be permitted.

- Rot and unsound wood are not permitted.

Raw Material

We used small, low-grade white oak timber to make the frame blanks. Large quantities of timber of this quality are available from thinning cuts and from logging residues in the eastern hardwood forests. Our timber came from one such thinning cut made during a study at the Forestry Sciences Laboratory (Craft and Baumgras 1979).

The thinning study was done on the Jefferson National Forest, Giles County, Virginia. A heavy cut reduced the stand from 111 square feet to 53 square feet of basal area per acre. Approximately 60 percent of the timber was white oak (*Quercus alba*). Trees to be removed were felled, limbed, topped at 4-inch dob (diameter outside bark), and bucked to roundwood products with the following priority: Factory Grade 2 or Better sawlogs, poles, 6-foot sawbolts, 4-foot sawbolts, pulpwood, and firewood. The distribution by volume for all species is shown in Table 2.

Primary Processing

Twenty-five hundred board feet (157 bolts) of 6-foot sawbolts were randomly selected from the thinning study. Each of the 157 bolts was numbered and sawed to cants; the cants were resawed to boards and the boards from each bolt numbered. The bolt and board data are shown in Table 3.

In System 6, bolts 6 feet long are sawed to two cants 6 feet long. In this study the cants were sawed either 3 or 4 inches thick and had two rounded sides. System 6 boards are resawed from the cants. All boards that had a minimum of one clear cutting 2 by 18 inches were kept. All boards from a 3-inch-thick cant are tallied as 3-inch-wide boards containing 1-1/2 board feet each. All boards from a 4-inch-thick cant are tallied as 4-inch-wide boards of 2 board feet each. So System 6 boards are not like the random-width, random-length boards that make up hardwood lumber.

Boards were immediately sticker stacked and strapped in 4-foot-wide packages using four 1/2-inch-thick stickers per layer. The stacks of green boards were put into a forced air predryer (Cuppett and Craft 1975) three stacks high with a concrete top weight. The concrete is 4 inches thick by 48 inches wide by 72 inches long and exerts about 50 pounds per square foot pressure to prevent drying distortion in the top layers. The weather was warm (75° to 80°F days; 60° to 65°F nights) and no supplemental heat was used during the 20 days of predrying. Moisture content (MC) after predrying averaged 22 percent. Ten days of kiln drying at mild temperatures followed by 8 hours of conditioning brought the oak boards to 6 percent MC. Drying quality was excellent.

After drying, the System 6 boards were divided into two groups by grade—those meeting or exceeding 3A Common grade and those not meeting the 3A Common grade. NHLA (National Hardwood Lumber Association) standard rules were used. NHLA rules require a one-third yield of clear-face cuttings of 3 by 24 inch minimum size to qualify a board for 3A Common grade. Any number of cuttings that equal or exceed minimum size may be used to meet the one-third yield requirement. A full 3-inch-wide System 6 board will qualify for 3A Common if only one minimum size cutting is found. One 3-1/2-inch-wide by 32-inch-long cutting, or two minimum

Table 2. Distribution of roundwood products from thinning two oak-hickory stands

Product	Percent of volume
Sawlogs (10-inch diameter by 8-feet long, Factory Grade 2 minimum)	20
Poles (6-inch diameter by 8-feet long minimum)	4
6-foot sawbolts (8- to 12-inch diameter by 75-inch length, sound, with 1-1/2-inch maximum sweep)	27
4-foot sawbolts (6-inch diameter minimum)	14
Pulpwood (5-foot length)	32
Firewood (random length)	3
Total	100

Data taken from Craft and Baumgras 1979.

Table 3. Primary processing yields

Bolt diameter		Bolts	Bolt scale[a]	Bolt scale	Cants		Total	System 6 boards		Overrun bolt/board[b]
Class	Range				3″ thick	4″ thick		board feet	% board feet	
- - - Inches - - -		*No.*	*fbm*	%	*- - - - No. - - - -*					%
7	6.6- 7.5	12	121	5	22	2	24	194	6	60
8	7.6- 8.5	57	688	27	110	4	114	919	28	34
9	8.6- 9.5	44	716	28	45	43	88	947	29	32
10	9.6-10.5	31	660	26	8	54	62	793	25	20
11	10.6-11.5	12	314	13	0	24	24	350	11	11
12	11.6-12.5	1	32	1	0	2	2	30	1	-6
Total		157	2531	100	185	129	314	3233	100	28

[a] International 1/4-inch rule: no deductions
[b] Overrun = [(Board footage - bolt scale)/bolt scale] × 100

size cuttings, will qualify a full 4-inch-wide System 6 board for 3A Common grade. In our study, all boards not meeting or exceeding the 3A Common minimums were classified as below grade. The quality of the boards was not good; 68 percent of the footage was below grade and only 32 percent was 3A Common or Better.

Secondary Processing

In this System 6 study, boards were nominally 3 or 4 inches wide, or from the outside of the cants and had waney edges, and all were 6 feet long. Most boards had many defects. Regular hardwood lumber rough mill (secondary processing) techniques—individual crosscuts and rips to remove defects—are too slow to be used with the small, poor quality System 6 boards. In System 6 the initial board crosscutting is ganged so that all cuts in one board are made at the same time. The initial ripcuts are made two at a time. In this way most of the poor wood is cut out rapidly. The resulting pieces are given an individual crosscut or ripcut if needed. The pieces, now free of objectionable defects, are edge-glued to blanks. The secondary processing steps are shown in Figure 2.

Figure 2.—Secondary processing.

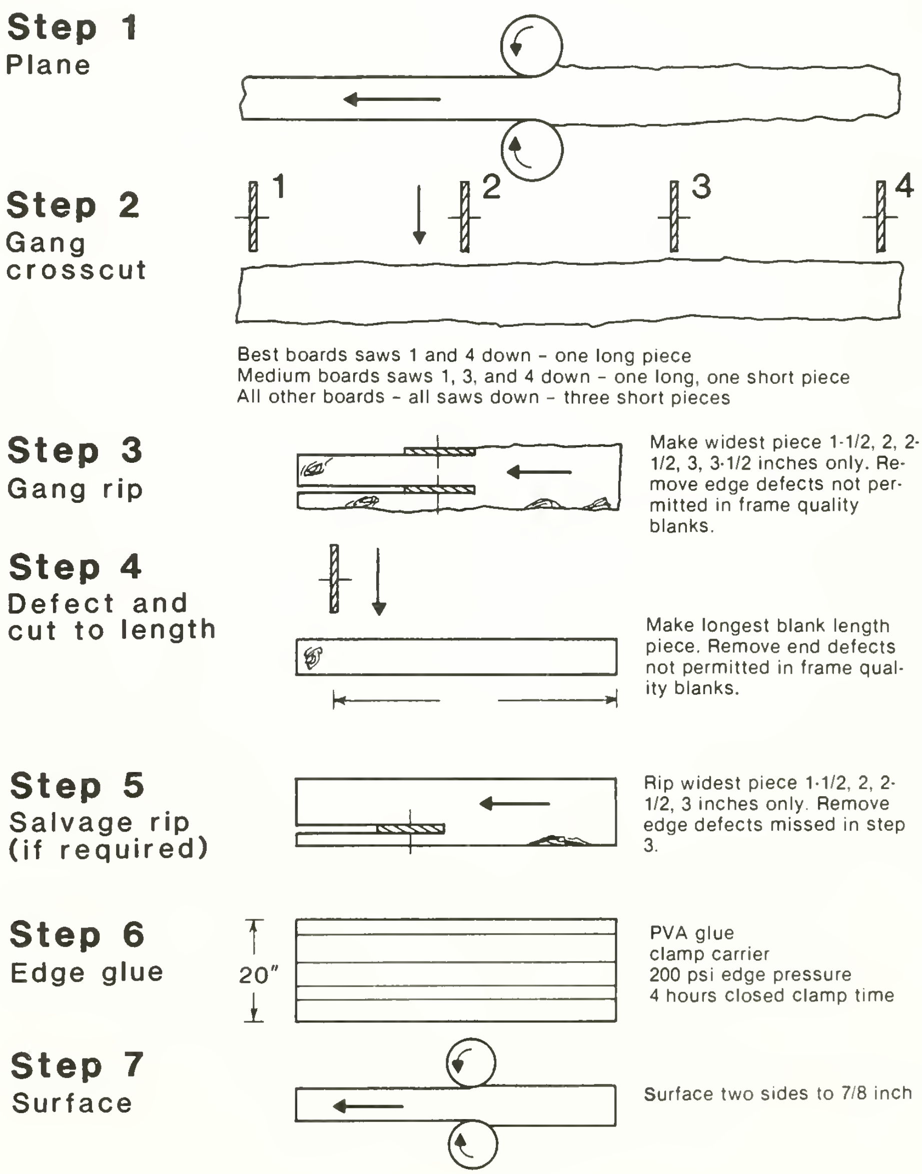


Table 4. Secondary processing instructions for each gang crosscutting length (All values in inches)

Secondary process	Gang crosscutting length			
	GCL–1 70, 44, 22	GCL–2 70, 33, 27	GCL–3 33, 29, 24	GCL–4 24, 22
Rough planing	Plane first side 0.975 inch; plane second side 0.940 inch abrasive planer			
Gang crosscut	Best: 72 Medium: 47, 25 Poor: 25, 22, 25	Best: 72 Medium: 39, 33 Poor: 20, 19, 33	Best Medium: Poor } 36, 36	Best Medium: Poor } 24, 24, 24
Gang ripsaw	1-1/2, 2, 2-1/2, 3, 3-1/2	1-1/2, 2, 2-1/2, 3, 3-1/2	1-1/2, 2, 2-1/2, 3, 3-1/2	1-1/2, 2, 2-1/2, 3, 3-1/2
Defect and trim to length	70, 44, 22 19, 17, 13	70, 33, 27 19, 17, 13	33, 29, 24 19, 17, 13	24, 22 19, 17, 13
Salvage ripsaw	1-1/2, 2, 2-1/2, 3	1-1/2, 2, 2-1/2, 3	1-1/2, 2, 2-1/2, 3	1-1/2, 2, 2-1/2, 3
Edge gluing[a]	70 × 20 44 × 20 22 × 20 19 × 20 17 × 20 13 × 20	70 × 20 33 × 20 27 × 20 19 × 20 17 × 20 13 × 20	33 × 20 29 × 20 24 × 20 19 × 20 17 × 20 13 × 20	24 × 20 22 × 20 19 × 20 17 × 20 13 × 20
Surfacing	Abrasive plane both sides to 0.875 inch (7/8 inch) final thickness			

[a] To standard blank sizes

We did not cut for all 11 blank-length pieces at one time. Instead we made four setups on the gang crosscut saw. In the first setup we cut to make 70-, 44-, and 22-inch blanks. This we called gang cross-cut length setup 1 (GCL-1). In the second we cut to make 70-, 33-, and 27-inch blanks (GLC-2). In the third we cut to make 33-, 29-, and 24-inch blanks (GCL-3). And in the fourth we cut to make 24- and 22-inch blanks (GCL-4). Pieces that could not be made to these lengths were made to 19-, 17-, and 13-inch blanks. Table 4 gives the step-by-step details for each of the four GCL's.

Four random samples of boards, 625 board feet each, were used to obtain yield data for each GCL. Each sample had 200 board feet of 3A Common and Better boards and 425 board feet of boards below 3A Common grade. Thus each sample was similar in quality composition—32 percent 3A Common and Better, 68 percent below grade—to the entire lot of boards sawed from the bolts.

For each GCL, the 3A Common and Better boards were processed first and then the below-grade boards. In this way we could determine the total blank yield by GCL and also the blank yield when only the below-grade boards were used. The yield results are shown in Table 5. (No 54-inch blanks were made with the GCL's used.)

Table 5. Blank yields by GCL and board quality (in percent)

GCL No.	Board quality	Total yield (%)	Yield by blank length in percent of total yield									
			70	44	33	29	27	24	22	19	17	13
1	All[a]	61.5	34.6	34.5					22.8	2.8	2.5	2.8
2	All	59.6	34.9		45.5		11.3			6.6	0.6	1.1
3	All	60.9			82.3	6.6		6.2		3.8	0.4	0.7
4	All	64.4						79.7	9.5	5.1	2.9	2.8
1	BG[b]	58.8	27.4	35.4					28.3	3.2	2.3	3.4
2	BG	55.8	24.7		50.6		15.3			7.2	0.6	1.6
3	BG	58.7			78.6	10.1		7.3		2.8	0.2	1.0
4	BG	63.2						78.9	8.2	6.7	3.0	3.2

[a] Yield data from boards 3A Common and Better combined with yield data from below-grade boards.
[b] Yield data from below-grade boards.

rocessing Control

So far this paper has been a traightforward report on a research tudy. Now we will shift gears and onsider means for using the yield ata (Table 5) to obtain the required uantity of blanks (Table 1). Processing control is needed to de- ermine the minimum number of oards to be cut by each GCL to ob- ain the blanks required.

The secret of efficient second- ry processing is to have long pro- uction runs. Blanks are made, in- entoried, and drawn from inventory s needed. More long blanks are nade than are needed and shorter lanks not in inventory are made by imming back the excess long blanks. One of the processing control requirements is to determine, in advance, how many long blanks are required for trimming.

Two techniques were developed to find the best combination of GCL's to obtain the required blanks. The first technique employs a computerized LP (linear programing) optimization; the second technique can be done by hand with a calculator. The LP technique gives the least board input answer and the computer cost is less than $1. The second technique approximates the LP answer but requires about 4 hours of manual calculations. Detailed explanations and instructions for both techniques are available from the authors.

Application of Processing Control

The yield values (Table 5) for all four GCL's, when all boards are used, were entered into the LP program. The blank length requirements (Table 1) were also entered. The least board footage to obtain the required blanks was 1,482 board feet. This LP solution is given in square feet, which is the same as board feet with 4/4 boards. The optimal LP solution chose to use only three GCL's. The quantity of blanks, in square feet, for each blank length for the three GCL's used is shown in Table 6.

The optimal combination of GCL's resulted in too many long blanks being made. Forty square feet of 70-inch blanks were required but 120 square feet were made. In this optimal combination, 169 square feet of 22-inch-long blanks were needed but only 85 square feet were made. The excess longer blanks were cut to fill the shortages of shorter blanks. The allocation of blanks for use and for trimming is given in Table 7.

Table 6. LP optimum distribution of blank lengths using all boards (in square feet)

Blank lengths (inches)	Gang cutting length			Total
	GCL-1	GCL-3	GCL-4	
70	120			120
44	119			119
33		414		414
29		34		34
24		31	48	79
22	79		6	85
19	10	19	3	32
17	8	2	2	12
13	10	3	1	14
Total	346	503	60	909
Area of boards used	563	826	93	1482
Percentage of total board area	38	56	6	100
Percent yield	61.5	60.9	64.4	61.3

Table 7. Area (in square feet) of blanks produced directly and by trimming, when all boards were used

Blank length (inches)	Blanks available	Blanks used without trimming	Blanks trimmed to or from other lengths	Blank waste	Blanks produced	Blanks required
70	120	40	32 cut to 25 × 54″ + 6 × 13″	1	40	40
			48 cut to 33 × 24″ + 15 × 22″	0		
54	0	0	25 from 70″ blanks		25	25
44	119	50	69 cut to 69 × 22″	0	50	50
33	414	110	102 cut to 89 × 29″	13	110	110
			202 cut to 166 × 27″	36		
29	34	34	89 from 33″ blanks		123	123
27	0	0	166 from 33″ blanks		166	166
24	79	79	33 from 70″ blanks		112	112
22	85	85	15 from 70″ blanks + 69 from 44″ blanks		169	169
19	32	32			32	Max. 83[a]
17	12	12			12	Max. 83
13	14	14	6 from 70″ blanks		20	Max. 39
Total	909	456	453 cut to 403	50	859	1000

[a] May be less than these values but no more.

Table 8. LP optimum distribution of blank lengths using below-grade boards only (in square feet)

Blank lengths (inches)	Gang cutting length			Total
	GCL-1	GCL-3	GCL-4	
70	89			89
44	115			115
33	0	395		395
29	0	50		50
24	0	37	64	101
22	92		7	99
19	10	15	5	30
17	7	1	2	10
13	11	4	3	18
Total	324	502	81	907
Area of boards used	552	855	128	1535
Percentage of total board area	38	56	6	100
Percent yield	58.8	58.7	63.2	59.1

The 909 square feet of total blanks (output) were made from 1,482 board feet (input), for a 61.3 percent yield. Fifty square feet of blanks were wasted (5.5 percent) in trimming the excess longer blanks to make up shortages of shorter blanks. This brought the final yield to 859 square feet or 58.0 percent of the input board footage.

The yield values (Table 5) for all four GCL's when only the below-grade boards were used were entered into a second run of the LP program. Again the blank length requirements (Table 1) were entered. The least board footage to obtain the required blanks was 1,535 board feet. The same three GCL's were used; the quantity of blanks in square feet per length for the three GCL's is shown in Table 8.

As before, the optimal combination of GCL's tested resulted in blanks for use directly and for trimming. The allocation of blanks for trimming and for use is given in Table 9.

Table 9. Area (in square feet) of blanks produced directly and by trimming, when only below-grade boards were used

Blank length (inches)	Blanks available	Blanks used without trimming	Blanks trimmed to or from other lengths	Blank waste	Blanks produced	Blanks required
70	89	40	32 cut to 25 × 54″ + 6 × 13″	1	40	40
			17 cut to 11 × 24″ + 5 × 22″	1		
54	0	0	25 from 70″ blanks		25	25
44	115	50	65 cut to 65 × 22″	0	50	50
33	395	110	83 cut to 73 × 29″	10	110	110
			202 cut to 166 × 27″	36		
29	50	50	73 from 33″ blanks		123	123
27	0	0	166 from 33″ blanks		166	166
24	101	101	11 from 70″ blanks		112	112
22	99	99	5 from 70″ blanks + 65 from 44″ blanks		169	169
19	30	30			30	Max. 83[a]
17	10	10			10	Max. 83
13	18	18	6 from 70″ blanks		24	Max. 39
Total	907	508	399 cut to 351	48	859	1000

[a] May be less than these values but no more.

The 907 square feet of total blanks (output) were made from 1,535 board feet of below-grade boards for a 59.1 percent yield. There were 48 square feet of blanks (5.3 percent) wasted in trimming the excess longer blanks to make up shortages of shorter blanks. This brought the final yield to 859 square feet of required blanks or 56.0 percent of the input board footage.

We also investigated using only GCL-1 or only GCL-2 to make all the required blanks. These yield results were higher than expected but were lower than the yields from using the three GCL combinations. When all boards were used, the yields were 45.5 percent with GCL-1 and 54.9 percent with GCL-2. When only boards below 3A Common grade were used, the yields were 43.3 percent with GCL-1 and 50.1 percent with GCL-2.

System 6 is designed for long secondary processing runs. Runs of 10,000 square feet of blanks would be typical. Having determined the requirements of blanks by length, such as those shown in Table 1, we can determine the quantity of boards needed for each GCL. The kiln-dried boards are brought to the secondary processing mill in stickered packages. System 6 boards, 4/4, 6 feet long have 400 square feet of boards per package. The instructions to the mill operators will be to cut a given number of packages at each GCL.

Consider a run of 10,000 square feet of blanks to meet the Table 1 requirements. An overall yield of 58.0 percent was found when all boards were used. Thus 10,000 ÷ 0.580 = 17,200 square feet of boards, so 43 packages will be required. GCL 1, 2, and 3 will be used with 16, 24, and 3 packages, respectively.

When only boards below 3A Common grade were used, the overall yield was 56.0 percent. Thus 10,000 ÷ 0.560 = 17,900 square feet of below-grade boards required. Since 68 percent of the boards are below grade, 17,900 ÷ 0.680 = 26,300 square feet of boards or 66 packages will be required. GCL 1, 2, and 3 will be used with 24, 37, and 5 packages, respectively. There will be 21 packages of 3A Common and Better boards available for processing to higher valued blanks.

Discussion

What do we need? What do we have to make it with? How should we convert what we have to what we want? In this study these questions are answered for 4/4 frame blanks made by System 6 from low-grade white oak timber.

The frame blank requirements for upholstered furniture and recliner needs were derived from Araman et al.'s work (1982). We made frame blanks to the sizes and quantities specified. Quality of the frame blanks was better than most furniture companies require. We took these blanks to a furniture company with a frame plant in central Tennessee. They ripped the blanks to parts and made frames for loveseats. The yield of parts from blanks was good, and the frames were excellent.

The bolts did not look good. They were small, with 72 percent 9-1/2 inches in diameter or less. Making frame blanks or frame and higher valued blanks would be the best use for this wood. Some loggers do not want to buck stems for multiple markets as shown in Table 1. If loggers wanted to make only short roundwood products, the sawlogs could be made to System 6 bolts. We could have obtained better quality and more footage if the small-diameter sawlogs had also been made to 6-foot-bolts. We obtained approximately 850 board feet per acre (International 1/4-inch rule) of white oak 6-foot sawbolts. Another 550 board feet could have been made from the sawlogs, bringing the total to 1,400 board feet per acre from this thinning job.

Although we obtained a very good quantity of boards (28 percent over bolt scale), the quality (68 percent below 3A Common grade) was poor. This quality level, however, is satisfactory for frame blank use. The large number of small-diameter bolts caused both the high overrun and low quality level. The high overrun is due to the inaccuracies of scaling 7-, 8-, and 9-inch bolts with the International 1/4-inch rule. For instance, a pile of 7-inch diameter 6-foot bolts that scaled 1,000 board feet total would actually yield 1,600 board feet of System 6 boards (see Table 3).

Other System 6 research in which the boards from each bolt were graded showed that small-diameter bolts gave lower average grade of boards. The boards from the small-diameter bolts had lower than average blank yields. If more large diameter bolts had been used, the overall quality of boards would have been better and overrun would have been reduced.

Two techniques were developed for determining, in advance, the quantity of System 6 boards to be processed, using a combination of GCL's to obtain the optimal yield. Production scheduling will go forward with board quantities per GCL specified. The only changes to be made between GCL's are the saw spacing setup on the gang crosscut saw. All pieces leaving the gang crosscut saw are made to the longest, widest frame quality pieces specified. Blanks are edge glued, planed, and inventoried. Blanks required that are not in inventory are made by trimming the longer blanks. Because this is planned for in advance, there will always be enough longer blanks available.

In some cases upholstery or recliner manufacturers may need a limited supply of clear blanks. When wood of the quality level we found in this white oak is used to make clear blanks, yields will be low. It would be desirable in that case to separate out the 32 percent of all boards that are 3A Common or Better and use them to produce clear quality blanks.

Using all the System 6 boards, the yield of frame blanks from board footage was 58.0 percent. When only the boards below 3A Common grade were used, the yield was 56.0 percent. The blank yield drops only 2.0 percent when only the below-grade boards are used. This yield difference is small because a large number of defects are permitted in frame quality blanks.

Conclusions

The white oak timber we used in this study was of marginal quality but was good enough to make frame blanks. If clear blanks only were made, yields would be too low. If frame and clear blanks are to be made from timber of this marginal quality, the better boards should be sorted out and used for the clear blanks. If all the white oak timber from the plot that met the System 6 specifications had been used, the overall quality would have been improved and more quantity per acre would have been obtained.

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Low-grade white oak timber, removed during a timber stand improvement cut on the Jefferson National Forest in Virginia, was made into sawlogs, poles, 6-foot bolts, 4-foot bolts, pulpwood, and firewood. The 6-foot bolts were sawed to two cants per bolt; cants were resawed to 4/4 System 6 boards; boards were dried to 6 percent moisture content and were then made into frame blanks using System 6 technology. The blanks were used by an upholstered furniture company to make frames and were found very satisfactory. Yields of required frame blanks were good, 56 percent, when only the poorest two-thirds of all boards were used. The better boards can be used to make clear-quality blanks.

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Keywords: Furniture manufacturing; lumber drying; hardwood dimension

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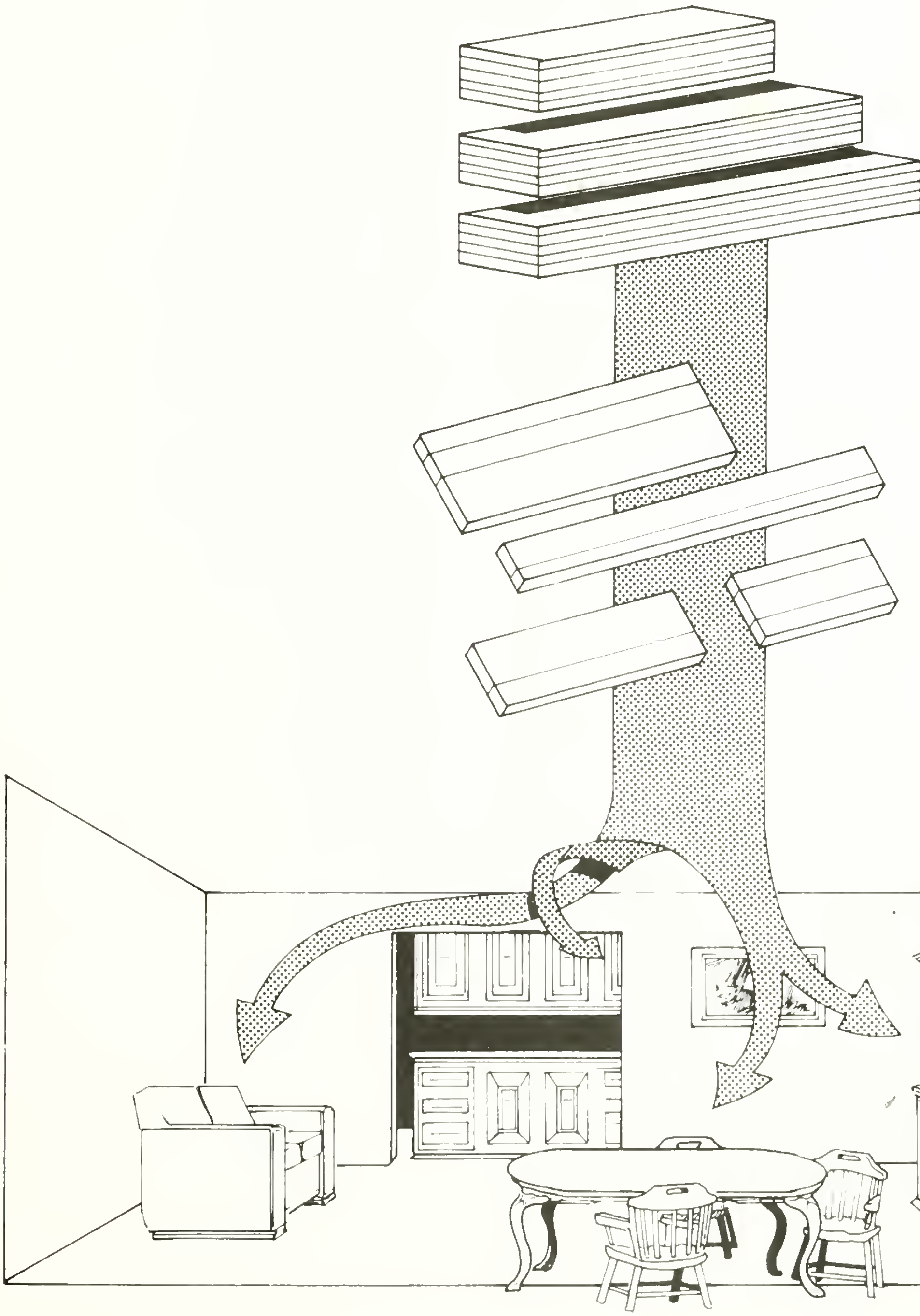
BLANKS: A Computer Program for Analyzing Furniture Rough-Part Needs in Standard-Size Blanks

Philip A. Araman



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Abstract

A computer program is described that allows a company to determine the number of edge-glued, standard-size blanks required to satisfy its rough-part needs for a given production period. Yield and cost information also is determined by the program. A list of the program inputs, outputs, and uses of outputs is described, and an example analysis with sample output is included.

Introduction

Standard-size, edge-glued blanks as input to the furniture manufacturing process is a new concept (Fig. 1). The concept calls for the use of a few standard sizes of ready-to-use, wide edge-glued blanks to produce the thousands of different parts required by a company (Araman et al. 1982). Before a company will adopt the use of blanks, it must be convinced of the merits of standard-size blanks.

A key question is: how well and at what cost do blanks meet the actual needs of my company? To provide the answer quickly through uniform individual analysis, we developed a computer program called BLANKS. The program determines the number of edge-glued, standard-size blanks required for each species-thickness-quality combination of rough parts specified by a company. The results from program BLANKS provide information on the number of standard-size blanks needed, yields, and costs, and describe a company's overall solid wood needs for a given production period.

In this report we present:

- A description of program BLANKS.
- The required program inputs.
- The program outputs.
- The uses of program outputs.
- An example analysis.

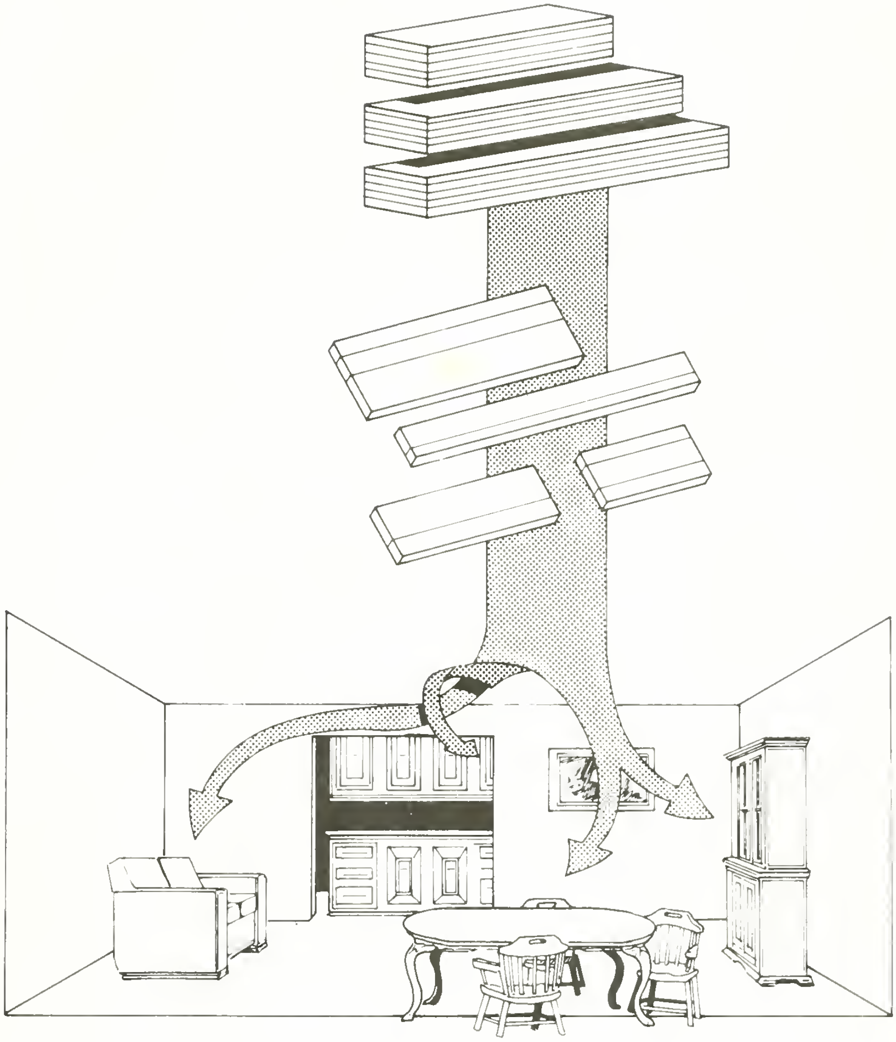

Figure 1.—In the standard blank concept, standard-size blanks are processed to rough-dimension parts that are used to make furniture and cabinets.

Program Description

Program BLANKS (see Appendix), written in FORTRAN, makes a separate analysis of the number of edge-glued standard-size blanks needed for each species-thickness-quality combination of parts required by a manufacturer. Part needs can be for a piece of furniture, any number of pieces in a suite or group of furniture, or for any combination of pieces of furniture.

In each analysis, the program:

- Simulates producing rough parts for one blank length at a time.
- Within a blank length, simulates producing parts starting with the widest part first, using 1/8-inch kerf saws. If needed, narrow parts are ripped from left over edgings. After the widest width cuttings are obtained, the next widest parts are processed. This is continued until all needs are satisfied.
- Tallies all pieces 1 inch and wider left over from the blanks. This material can be recycled into new blanks.
- Calculates yield, regluable material, end-trim waste, edge and kerf waste, and total waste, in percentages, for each blank size. It also provides totals for each species-thickness-quality combination.
- Calculates dollar values for the parts produced and for the regluable materials. Values are based on square foot on input in standard-size blanks.

Results are printed by program BLANKS after all parts are satisfied. A summary table shows what is needed by standard blank size and in total, including number of blanks needed, yields, and costs.

Program Inputs

The input data required include standard blank sizes (from Table 1) and their value per square foot, along with the rough-part lengths, widths, and quantities needed. Quantities needed are determined by multiplying the number of parts needed for the item times the number of items needed for the production period. The following steps must be taken to prepare the input data for program BLANKS.

1. For each different part size needed, prepare a part size data card with the following information:

Item	*Columns*	
Part length	4–9	Right justify or include decimal point (applies to part length and part width)
Part width	11–16	
Quantity neded	17–20	Must right justify
Group number	21–72	Choose your own format (This information is not used by the computer program but is needed to arrange the data cards in the next step, which must be done manually.) (applies to group number, input lumber thickness, species needed, quality)
Input lumber thickness		
Species needed		
Quality		

2. Arrange part-size data cards by lumber species-thickness-quality.

3. Sort the part-size data cards within each species-thickness-quality by standard lengths. For example, all 4/4 clear parts up to 15 inches long would go into the 15-inch group, all parts over 15 inches and up to 18 inches long would go into the 18-inch group, and so on.

4. Arrange the part-size data cards within each standard length group by part width—widest to narrowest.

5. For each standard-size blank prepare a data card with the following information:

Item	*Columns*	
Blank length	7–12	
Blank width	13–18	
Blank value/square foot	19–24	(estimate of internal production value or outside purchase price)

Table 1.—Recommended hardwood blank standard sizes for furniture and cabinet manufacturers (in inches)

Nominal thickness	Intended product finish thickness	Actual blank thickness	Blank lengths												
			Clear Quality/26-Inch-Wide Blanks												
5/8	3/8	1/2	13	15	17	18	22	26	31	36	42	—	—	—	—
3/4	1/2	5/8	14	17	19	22	25	29	31	35	41	47	58	86	—
4/4	3/4	7/8	15	18	21	25	29	33	38	45	50	60	75	100	—
1-1/4	1	1-1/8	15	18	21	25	29	33	38	45	50	60	75	100	—
1-1/2	1-1/4	1-3/8	15	18	21	25	28	32	35	40	45	50	60	70	85
2	1-5/8	1-3/4	15	18	21	25	28	32	35	40	45	50	60	70	90
			Core Quality/26-Inch-Wide Blanks												
1	3/4	7/8	15	18	21	23	26	29	34	40	50	60	70	95	—
1-1/4	1	1-1/8	15	18	21	23	26	29	34	40	50	60	70	85	—
			Sound Frame Quality (for upholsterd frames)/20-Inch-Wide Blanks												
1	3/4	7/8	13	17	19	22	24	27	29	33	44	54	70	80	100
1-1/4	1	1-1/8	15	18	20	23	25	28	33	45	55	65	80	90	100
1-1/2	1-1/4	1-3/8	14	18	21	24	28	31	34	40	—	—	—	—	—
2	1-5/8	1-3/4	12	16	19	21	24	28	30	34	—	—	—	—	—
			Sound Interior Quality (for case goods)/20-Inch-Wide Blanks												
1	3/4	7/8	15	18	21	25	29	34	40	50	60	70	95	—	—

Blank sizes other than the recommended sizes in Table 1 can be used here.

6. Arrange the input data in the following sequence for each species-thickness-quality analysis:

a. First standard-size blank data card.

b. A card stating in columns 1-2 (right justified) the number of part cards that will follow for this standard size.

c. The part cards.

d. A continuation or stop card—if column 1 contains a 1, the program will continue; if it contains a 2, the program will stop and provide a summary printout.

e. Continued sets of cards a, b, c, and d until all standard length sets have been placed in the card deck. Make sure that card d has a 2 in column 1 in the last set of cards.

Program Outputs

After the simulator has produced all of the required parts from blanks, summaries are calculated and the results are printed. Included in the printout for each blank size (L x W) are: number needed, square feet of blanks used, square feet of parts produced, percent yield of parts, total cost of the parts, percent regluable material, regluable material value, percent end-trim waste, percent edge and ripping waste, and percent total waste. Totals for each species-thickness-quality combination also are provided.

Uses of Output

The blanks-to-parts results generated by program BLANKS can be used by a manufacturer in many ways. The information allows a manufacturer to take a good look at what is needed in rough dimension or, more specifically:

- Evaluate standard-size blanks as a solid wood input material.
- Consider and develop a blanks inventory system.
- Decide what to make or buy and inventory as standard-size blanks.
- Decide what to make or buy in exact rough-part dimensions if total adoption of the standard sizes is not desired.

- Decide which low-demand species-thickness parts should be made with a more highly demanded species-thickness.

Program BLANKS also can be used to determine improvements in blanks-to-parts yield when the rough-part lengths are shortened, so shorter standard blank lengths can be used. The blanks should be manufactured precisely so that rough-to-finish part end-trim allowances can be reduced.

The program could be used in the planning stages for new furniture groups. The groups could be designed with the standard sizes and then analyzed by program BLANKS on the basis of cost and yield before production. In these stages, the program might be used to test for improved yields and reduced costs due to slight design changes.

Example Analysis

We used program BLANKS to analyze the 90-day needs for a manufacturer of occasional tables and other living room furniture. The manufacturer wanted to know if the use of standard blanks would be beneficial, specifically, he wanted to know how many blank sizes he would have to use and what his yields would be. He also wanted to get an idea of the inventories of blanks that would have to be maintained, and, among other things, determine the reduction in conversion losses if his product engineers modified slightly (no more than 1/2 inch) some part-length requirements. Lastly, he wanted to get a better idea of his overall part requirements.

This manufacturer produced furniture for 14 different suites or groups (A–N) during the selected 90-day production period. Over 261 different designs, mostly tables, had to be made. A total of 39,800 pieces of furniture were made during the 90-day production period. To make this furniture, six species and 25 species-thickness-quality combinations were required.

After preparing the input data cards, we ran each species-thickness-quality combination requirement by suite of furniture. Program BLANKS was used to analyze 102 sets of requirements. One of the summary output listings provided to the manufacturer is shown in Table 2.

After all of the runs were completed, we summarized the blank requirements for each species-thickness-quality combination. Table 3 shows the results for the 4/4 cherry clear-quality blank needs. The totals tell the company what its 90-day needs would be.

So that the manufacturer could see the improvements possible if his rough-part lengths could be reduced, we ran additional simulations with adjusted data. We reviewed the Group B 4/4 cherry requirements, where the part length was 1/2 inch or less longer than the standard length, we reduced the part length to the standard length and reran BLANKS. Table 2 presents the original results and Table 4 the adjusted results.

The changes gave us better conversion utilization, lower costs, and more demand for shorter blank lengths. The increased demand for shorter blanks and a decreased need for longer blanks caused the total surface area to go down and the yield to go up. The total cost went down along with the waste. Material that could be reglued into panels (last ripping cuts over 1 inch wide) increased. End-trim waste dropped from 5 to 3 percent.

After analyzing these results, the manufacturer was convinced of the merits of the blanks concept and has developed for implementation a completely new rough-mill processing and inventory system. When implemented, new groups of furniture will be designed with the standard blank sizes, and rough-part sizes currently needed may be changed to take advantage of the standard sizes.

Summary

Program BLANKS allows manufacturers to quickly analyze their rough-part requirements as if they were being produced from a few standard sizes of ready-to-use, edge-glued blanks. With information on the number of blanks needed, yields, and costs, manufacturers can evaluate standard-size blanks as a solid wood input material and decide on total or partial adoption of this concept. The output from program BLANKS also aids manufacturers in better understanding rough-part needs and costs.

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Table 2.—Parts from standard-size blanks summary—Group B 4/4 cherry clear-quality requirements

Blank size (inches)	Number needed	Blank	Parts	Percent yield	Total cost	Percent reglu-able	Reglu-able value	Percent end waste	Percent edge waste	Percent total waste
		----- ft²	-----		*Dollars*		*Dollars*			
15 × 26	16	43	36	0.83	63.27	0.01	0.83	0.07	0.09	0.15
18 × 26	137	445	376	0.85	650.06	0.00	1.25	0.08	0.07	0.15
21 × 26	75	284	259	0.91	415.19	0.00	0.87	0.04	0.05	0.09
25 × 26	25	113	90	0.80	164.76	0.04	5.96	0.09	0.07	0.16
29 × 26	58	304	255	0.84	443.39	0.01	5.32	0.07	0.08	0.15
33 × 26	44	262	241	0.92	382.76	0.01	4.16	0.00	0.07	0.07
38 × 26	78	535	454	0.85	781.34	0.01	8.71	0.05	0.09	0.14
Total	433	1987	1712	0.86	2900.78	0.01	27.10	0.05	0.08	0.13

Table 3.—Summary of company's 90-day 4/4 cherry clear-quality needs in standard-size blanks

Group	Number of blanks required									
	15 × 26	18 × 26	21 × 26	25 × 26	29 × 26	33 × 26	38 × 26	45 × 26	50 × 26	60 × 26
A	—	—	—	—	—	—	—	—	—	—
B	16	137	75	25	58	44	78	—	—	—
C	—	—	—	—	—	—	—	—	—	—
D	849	1906	959	1818	622	277	16	51	203	38
E	—	—	—	—	—	—	—	—	—	—
F	72	148	167	106	25	—	—	—	54	—
G	—	—	—	—	—	—	—	—	—	—
H	204	120	115	772	50	19	400	25	—	—
I	95	35	86	379	27	—	300	37	—	—
J	—	—	—	—	—	—	—	—	—	—
K	—	—	—	—	—	—	—	—		—
L	—	—	—	—	—	—	—	—	—	—
M	310	70	185	54	9	7	9	—	27	—
N	—	—	—	—	—	—	—	—	—	—
Total	1546	2416	1587	3154	791	347	803	113	284	38

Table 4.—Parts from standard-size blanks summary—Group B 4/4 cherry clear-quality requirements after changes made in rough-part lengths

Blank size (inches)	Number needed	Blank	Parts	Percent yield	Total cost	Percent reglu-able	Reglu-able value	Percent end waste	Percent edge waste	Percent total waste
		--- ft²	---		Dollars		Dollars			
15 × 26	79	214	192	0.90	312.38	0.00	0.00	0.01	0.09	0.10
18 × 26	80	260	218	0.84	379.60	0.11	41.70	0.02	0.03	0.05
21 × 26	75	284	259	0.91	415.19	0.00	0.87	0.04	0.05	0.09
25 × 26	50	226	192	0.85	329.51	0.02	5.73	0.04	0.09	0.13
29 × 26	33	173	151	0.87	252.28	0.02	5.70	0.03	0.07	0.11
33 × 26	59	352	316	0.90	513.25	0.01	6.81	0.00	0.09	0.09
38 × 26	64	439	378	0.86	641.10	0.01	8.44	0.04	0.09	0.13
Total	440	1947	1706	0.88	2843.31	0.02	69.24	0.03	0.07	0.10

Appendix

Note to Programers

Program BLANKS can be run in a batch or an interactive mode. Data input prompts have been placed in the program to aid those who use an interactive system. These prompts and some intermediate printing of results also will appear in the batch mode printouts and can be eliminated by removing the following cards: BLNK 33, BLNK 38, BLNK 44, BLNK 125, BLNK 130, BLNK 131, BLNK 172, BLNK 174, BLNK 176, BLNK 177, BLNK 179, BLNK 180, BLNK 181, and BLNK 182.

```
C***********************************************************************BLNK   1
C                                                                       BLNK   2
C      PROGRAM BLANKS                                                   BLNK   3
C                                                                       BLNK   4
C      PROGRAMMER: P.A. ARAMAN                DATE: JULY 14,1982        BLNK   5
C                  U.S. FOREST SERVICE                                  BLNK   6
C                  PRINCETON, WV                                        BLNK   7
C                                                                       BLNK   8
C      PROGRAM SIMULATES MAKING ROUGH DIMENSION PARTS FROM STANDARD-SIZE BLNK   9
C      BLANKS.  THE PROGRAM COMPILES AND PRINTS A SUMMARY OF THE RESULTS.BLNK  10
C***********************************************************************BLNK  11
       INTEGER NN(50),BLANKS,B,LPC,BBLANK(50)/50*0/,B1,NNE(50)          BLNK  12
       REAL LT(50),WT(50)/50*0./,SBLT(50)/50*0./,SBWT(50)/50*0./,SBSQFT(5BLNK  13
      10)/50*0./,SCSQFT(50)/50*0./,SUTILP(50)/50*0./,STCOST(50)/50*0./,SRBLNK  14
      2EGP(50)/50*0./,SRGVAL(50)/50*0./,SWASTP(50)/50*0./,SETRIM(50)/50*0BLNK  15
      3./,SKERFE(50)/50*0./                                             BLNK  16
       B1=0                                                             BLNK  17
       I5=0                                                             BLNK  18
       S1=0.                                                            BLNK  19
       S2=0.                                                            BLNK  20
       S3=0.                                                            BLNK  21
       S4=0.                                                            BLNK  22
       S5=0.                                                            BLNK  23
       W1=0.                                                            BLNK  24
20     BLANKS=0.                                                        BLNK  25
       REGLUE=0.                                                        BLNK  26
       WASTE=0.                                                         BLNK  27
       CSQFT=0.                                                         BLNK  28
       ETRIM=0.                                                         BLNK  29
C                                                                       BLNK  30
C      READ STANDARD BLANK LENGTH, WIDTH AND PRICE                      BLNK  31
C                                                                       BLNK  32
       WRITE (6,210)                                                    BLNK  33
       READ (5,220) BLT,BWT,BPRICE                                      BLNK  34
C                                                                       BLNK  35
C      READ NUMBER OF DIFFERENT CUTTINGS THAT FOLLOW TO BE READ         BLNK  36
C                                                                       BLNK  37
       WRITE (6,230)                                                    BLNK  38
       READ (5,240) N                                                   BLNK  39
C                                                                       BLNK  40
C      MUST READ IN WIDEST TO NARROWEST WIDTH                           BLNK  41
C      LENGTHS CAN BE OUT OF ORDER                                      BLNK  42
C                                                                       BLNK  43
       WRITE (6,250)                                                    BLNK  44
C                                                                       BLNK  45
C      READ CUTTINGS NEEDED                                             BLNK  46
C                                                                       BLNK  47
       DO 30 I=1,N                                                      BLNK  48
       READ (5,260) III,LT(I),WT(I),NN(I)                               BLNK  49
       CSQFT=(LT(I)*WT(I)*NN(I))/144.+CSQFT                             BLNK  50
       ETRIM=ETRIM+((BLT-LT(I))*WT(I)*NN(I))/144.                       BLNK  51
30     NNE(I)=NN(I)                                                     BLNK  52
       DO 190 I=1,N                                                     BLNK  53
       IF (NNE(I).LE.0) GO TO 190                                       BLNK  54
       B=BWT/(WT(I)+.125)                                               BLNK  55
```

```
      BCHECK=B*(WT(I)+.125)+WT(I)
      IF (BCHECK.LE.BWT) B=B+1
      BN=FLOAT(NNE(I))/FLOAT(B)
      IF (BN-IFIX(BN).EQ.0.) GO TO 40
      BN1=1-(BN-IFIX(BN))
      GO TO 50
40    BN1=0.
50    IF (BN1.GT.0) BLANKS=BLANKS+1
      BLANKS=BLANKS+BN
      NNE(I)=0
C
C     BN1 IS FRACTION OF LAST BLANK LEFT
C
      W=BWT-B*(WT(I)+.125)
      IF (W.GE.1.) GO TO 60
      WASTE=WASTE+IFIX(BN)*W
      GO TO 150
60    IF (I.LT.N) GO TO 90
      GO TO 80
70    II=II+1
      IF (II.GT.N) GO TO 80
      GO TO 100
80    REGLUE=REGLUE+IFIX(BN)*W*BLT
      GO TO 150
C
C     CAN EDGING BE USED
C
90    II=I+1
100   IF (WT(II).GT.W) GO TO 70
      IF (NNE(II).LE.0) GO TO 120
      BS=W/(WT(II)+.125)
      BND=NNE(II)/BS
      IF (BND.LT.BN) GO TO 110
      NNE(II)=NNE(II)-IFIX(BS)*IFIX(BN)
C
C      REDEFINE W AFTER SECONDARY CUTTINGS HAVE BEEN REMOVED AMR
C
      W=W-(WT(II)+.125)*IFIX(BS)
      IF (W.GE.1) GO TO 70
      GO TO 150
110   NNE(II)=0
      IF (II.EQ.N) GO TO 130
      BN=BN-BND
120   II=II+1
      IF (II.GT.N) GO TO 80
      GO TO 100
130   REGLUE=REGLUE+BLT*W*(BN-BND)
      GO TO 190
140   REGLUE=REGLUE+BLT*BN1*BWT
      GO TO 190
C
C     USE FRACTION OF LAST BLANK
C
150   IF (BN1.EQ.0) GO TO 190
      II=I+1
```

```
160   IF (II.GT.N) GO TO 140
      IF (NNE(II).GT.0) GO TO 170
      II=II+1
      GO TO 160
170   LPC=(BN1*BWT)/(WT(II)+.125)
      IF (LPC.GT.NNE(II)) GO TO 180
      NNE(II)=NNE(II)-LPC
      BN1=0.
      GO TO 190
180   BN1=((BN1*BWT)-(WT(II)+.125)*NNE(II))/BWT
      NNE(II)=0
      GO TO 140
190   CONTINUE
      TCOST=BLANKS*BPRICE*BLT*BWT/144.
      WRITE (6,270) BLT,BWT,BLANKS,BPRICE,TCOST
      BVOL=BLANKS*BLT*BWT/144.
      REGP=REGLUE/144./BVOL
      REGLUE=REGLUE/144.
      UTILP=CSQFT/BVOL
      WRITE (6,280) CSQFT,UTILP,REGLUE,REGP
      WRITE (6,290)
      READ (5,300) N5
      I5=I5+1
      SBLT(I5)=BLT
      SBWT(I5)=BWT
      SBSQFT(I5)=BVOL
      SCSQFT(I5)=CSQFT
      SUTILP(I5)=UTILP
      BBLANK(I5)=BLANKS
      STCOST(I5)=TCOST
      SREGP(I5)=REGP
      SRGVAL(I5)=TCOST*REGP
      SETRIM(I5)=ETRIM/BVOL
      SWASTP(I5)=1.-UTILP-REGP
      SKERFE(I5)=SWASTP(I5)-SETRIM(I5)
      S1=S1+SBSQFT(I5)
      S2=S2+SCSQFT(I5)
      S3=S3+REGLUE
      S4=S4+TCOST
      S5=S5+TCOST*REGP
      B1=B1+BLANKS
      W1=W1+ETRIM
      IF (N5.EQ.1) GO TO 20
C
C     WRITE RESULTS
C
      WRITE (6,310)
      WRITE (6,320)
      DO 200 I6=1,I5
      WRITE (6,330) SBLT(I6),SBWT(I6),BBLANK(I6),SBSQFT(I6),SCSQFT(I6),S
     1UTILP(I6),STCOST(I6),SREGP(I6),SRGVAL(I6),SETRIM(I6),SKERFE(I6),SW
     2ASTP(I6)
200   CONTINUE
      CYIELD=S2/S1
      RYIELD=S3/S1

      WYIELD=1.-CYIELD-RYIELD
      W12=W1/S1
      W13=WYIELD-W12
      WRITE (6,340) B1,S1,S2,CYIELD,S4,RYIELD,S5,W12,W13,WYIELD
      STOP
C
210   FORMAT (1H0,24HBLANK LENGTH WIDTH PRICE)
220   FORMAT (6X,F6.0,F6.0,F6.0)
230   FORMAT (1H0,37HNO. OF DIFFERENT CUTTINGS TO BE READ?)
240   FORMAT (I2)
250   FORMAT (1H0,35HMUST BE READ IN WIDEST TO NARROWEST/1H ,4X,18HLENGT
     1H WIDTH   NO.)
260   FORMAT (I1,2X,F6.0,1X,F6.0,1X,I4)
270   FORMAT (1H0,F6.0,1HX,F6.0,4X,I4,4X,3H@ $,F6.2,3H= $,F8.2)
280   FORMAT (1H0,6HCSQFT=,F8.2/1H0,19HBLANKS UTILIZATION=,F4.2/9H0
     1    ,20HREGLUEABLE MATERIAL=,F8.2/1H0,15HREGLUEABLE PCT=,F4.2)
290   FORMAT (1H0,45HIF ANOTHER RUN IS NEEDED TYPE 1 IF NOT TYPE 2)
300   FORMAT (I1)
310   FORMAT (1H1///)
320   FORMAT (1H0,7HSUMMARY/1H0,96HBLANK   BLANK   NUMBER   BLANK   PART
     1S   %      TOTAL   %         REGLUE  % END  % EDGE  % TOTAL/1H ,94
     2HLT       WT       NEEDED    SQFT     SQFT     YIELD    COST     REGLUE
     3 VALUE    WASTE   WASTE    WASTE/1H ,96H-----------------------------
     4-----------------------------------------------------------------
     5-)
330   FORMAT (1H0,F4.0,5X,F3.0,I7,5X,F7.0,1X,F7.0,2X,F4.2,1X,F8.2,3X,F4.
     12,3X,F7.2,4X,F4.2,4X,F4.2,4X,F4.2)
340   FORMAT (1H0,96H-------------------------------------------------------
     1-------------------------------------/1H0,6HTOTALS,9X,I5,2
     2X,F9.0,F9.0,1X,F4.2,1X,F8.2,3X,F4.2,3X,F7.2,4X,F4.2,4X,F4.2,4X,F4.
     32)
      END
```

Araman, Philip A. BLANKS: A computer program for analyzing furniture rough-part needs in standard-size blanks. Res. Pap. NE-521. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 8 p.

A computer program is described that allows a company to determine the number of edge-glued, standard-size blanks required to satisfy its rough-part needs for a given production period. Yield and cost information also is determined by the program. A list of the program inputs, outputs, and uses of outputs is described, and an example analysis with sample output is included.

ODC 836.1: 854.1

Keywords: Furniture rough-part sizes; cabinet rough-part sizes; hardwood lumber; panels

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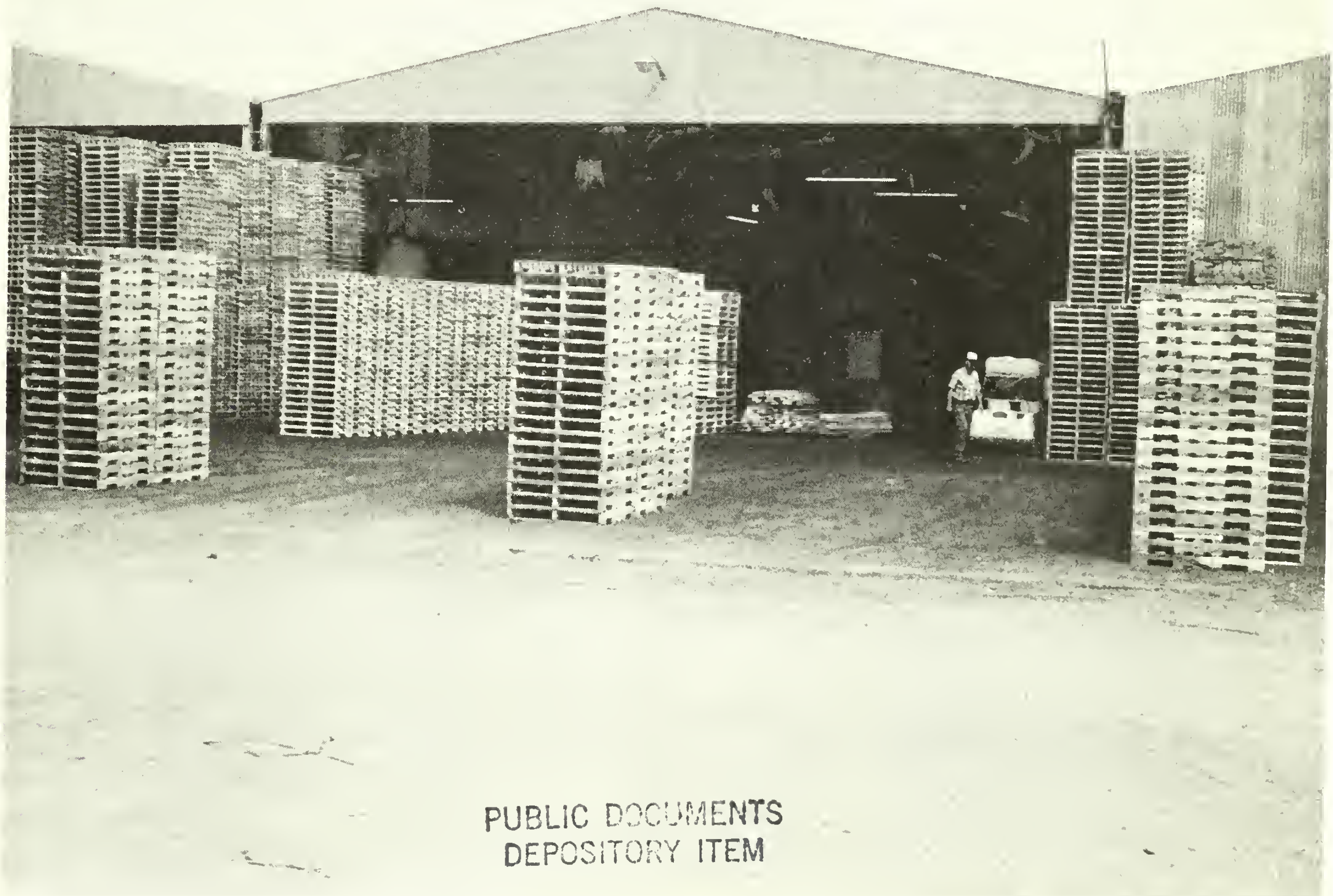
A Revised Econometric Model of the Domestic Pallet Market

Albert T. Schuler
Walter B. Wallin



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Abstract

The purpose of this revised model is to project estimates of consumption and price of wooden pallets in the short term. This model differs from previous ones developed by Schuler and Wallin (1979 and 1980) in the following respects: The structure of the supply side of the market is more realistically identified (from an economic theory point of view) by including lagged relationships; more recent data are incorporated into the data base; and the statistical correlation is improved.

The model is intended to provide reliable estimates of the quantity of pallets required and their real price over a relatively short term of 1 to 5 years. It is not intended to be used in determining policy concerning the growth or decline of palletization in materials handling.

The pallet industry consumes about 15 percent of the total U.S. lumber production and over 50 percent of the hardwood lumber production. Pallet demand has increased at an average annual rate of 8 percent since the mid-1950's. Because the pallet industry provides the largest volume market for hardwoods, it has an important effect on the utilization of the entire hardwood resource.

An econometric model is useful to both industry and government. This one can be used to provide quantitative information on the performance and structure of the pallet market; to identify the most important factors which are correlated with consumption and price of pallets; to make short-term projections of consumption and price needed to formulate plans for plant operations, sales, and raw material procurement; and to assess the demand on the forest resource.

This report describes an improved version of the model of the domestic pallet market which evolved from two earlier versions (Schuler and Wallin 1979; Schuler and Wallin 1980). It is the result of an ongoing effort to keep the model updated and to improve its effectiveness and reliability.

Model Development and Evaluation

Tables 1 and 2 list major factors assumed to affect pallet demand and supply, initial candidate variables selected to represent these factors, expected relationships between the variables and demand and supply (based on economic theory), and their units of measurement. The data base was annual observations of each variable over the sample period 1960 to 1980.

The data and sources used were as follows: for pallet price, pallet production, and wage rates in the pallet industry—annual reports of the National Wooden Pallet and Container Association, Washington, D.C.; for the industrial production index and wage rates of labor in materials handling—U.S. Bureau of the Census, 1960–1980; for price of red oak lumber—Hardwood Market Report, weekly, 1960–1980; and for productivity in the pallet industry—U.S. Bureau of the Census, 1954–1977 and U.S. Bureau of the Census, 1970–1980.

The parameters for the demand and supply equations were estimated using the three-stage least squares procedure of Zellner and Theil (1962). It is an equilibrium-type model because we assume that demand = supply for the time period (1 year) used in our analysis. It is a simultaneous-equation model because we assume that demand, supply, and price of pallets are determined simultaneously (in our 1-year time period). Discussions with people knowledgeable of the structure of the pallet market and our observations confirm the assumptions of an equilibrium-type simultaneous-equation model.

The Model

Standard errors and associated t-statistics are given in Table 4.

$$\begin{aligned}\text{Pallet demand (1,000 units)} = {} & 152{,}364 - 61{,}741\ \text{Pallet price} \\ & + 2{,}914\ \text{Industrial production index} \\ & - 97{,}131\ \text{Pallet substitute}\end{aligned} \qquad (1)$$

DW = 1.30

$$\begin{aligned}\text{Pallet supply (1,000 units)} = {} & -584{,}119 + 428{,}484\ \text{Pallet price} \\ & - 3{,}055\ \text{Red oak lumber price} \\ & - 493{,}492\ \text{Pallet labor cost} \\ & + 131{,}319\ \text{Productivity}\end{aligned} \qquad (2)$$

DW = 1.72

The demand and supply equations were then solved simultaneously to yield reduced form equations suitable for projecting pallet consumption and price.

$$\begin{aligned}\text{Pallet consumption (1,000 pallets)} = {} & 59{,}609 + 2{,}547\ \text{Industrial production index} \\ & - 84{,}898\ \text{Pallet substitute} \\ & - 385\ \text{Red oak lumber price} \\ & - 621\ \text{Pallet labor cost} \\ & + 16{,}539\ \text{Productivity}\end{aligned} \qquad (3)$$

$$\begin{aligned}\text{Pallet price (\$ 1967/unit)} = {} & 1.50 + 0.006\ \text{Industrial production index} \\ & - 0.198\ \text{Pallet substitute} \\ & + 0.0062\ \text{Red oak lumber price} \\ & + 1.007\ \text{Pallet labor cost} \\ & - 0.268\ \text{Productivity}\end{aligned} \qquad (4)$$

Discussion

The model, equations (1) and (2), is a good model from both economic and statistical perspectives. It is good from an economic viewpoint because each variable had the sign expected from economic theory of the firm. It is good from a statistical viewpoint because each variable was significant at the 0.07 percent level or better, the beta coefficients were at least twice as large as their standard errors, and no serial correlation was shown by the Durbin-Watson D-statistic. There was covariance across equations (1) and (2); therefore, the three-stage least squares estimating procedure provided parameter estimates with smaller standard errors than the two-stage least squares procedure.

All price variables in the model were converted to 1967 dollars (deflated by the Producer Price Index for all commodities) because models estimated with nominal price data produced variables with incorrect signs (according to the economic theory of the firm) and weaker statistical correlations than the deflated price variables.

The consumption and price projection equations, (3) and (4), were evaluated to determine how closely they fitted the sample data (Table 3). If the equations fit the sample data closely, then they should provide a good means for projecting pallet consumption and price beyond the data base, at least for a few years. However, our projection equations are reduced-form equations and not regression equations. Therefore, we cannot evaluate their consistency over time or their predictive power by standard statistical methods. Some commonly used measures of "goodness of fit" for reduced-form equations are Theil's U-coefficient and mean absolute percentage error.

Table 1.—Major demand factors, variables, expected relationships between variables and demand, and units for the pallet model. The names in parentheses in the variable column are those used in equations 1 through 4

Factor	Variable	Expected relationship	Unit
Pallet demand	Pallet consumption	—	1000 pallets
Pallet price	Mill realization/price which equals total dollar volume of sales ÷ total units produced. Sales are in 1967 dollars (Pallet price)	Positive	$ 1967/pallet
U.S. industrial and food production activity—a proxy for price of output of the demanding industry	An index of the weighted average production of durable (25%) and non-durable manufactured goods (Industrial production index)	Positive	Index (1967 = 100)
Price of substitute for pallets	A 3-year moving average of the ratio of pallet price to manual labor wage rate (Pallet substitute)	Negative[a]	Ratio

[a] Ordinarily one would expect the relationship to be positive for a true substitute good, however, because of the construction of the variable, we would expect the relationship to be negative.

Table 2.—Major supply factors, variables, expected relationships, and units for the pallet model. The names in parentheses in the variable column are those used in equations 1 through 4

Factor	Variable	Expected relationship	Unit
Pallet supply	Pallet consumption	—	1000 pallets
Pallet price	Mill realization price which equals total dollar volume of sales ÷ total units produced. (Sales are in 1967 dollars) (Pallet price)	Positive	$ 1967/pallets
Production costs	A 2-year moving average, lagged 1 year, of grade 3A red oak lumber (Red oak lumber price)	Negative	$ 1967/Mbf
	A 2-year moving average, lagged 1 year, of hourly wage rates of pallet production workers (Pallet labor cost)	Negative	$ 1967/hour
	Productivity in the pallet industry (Productivity)	Positive	Pallets/man-hour

Table 3.—U-coefficient, mean absolute percentage error (MAPE), and mean percentage error (MPE) for the revised model and the previous model

Model	U-coefficient[a]	MAPE[b]	MPE[c]
		Percent	*Percent*
1. Revised model			
Consumption (1000 pallets)	0.41	5.4	<1
Price ($ 1967/pallet)	0.69	4.5	<1
2. Previous model (Schuler & Wallin 1980)			
Consumption (1000 pallets)	0.52	7.4	4.0
Price ($ 1967/pallet)	0.64	4.5	<1

$P_i = P_t - A_{t-1}$
$A_i = A_t - A_{t-1}$
P_t = Predicted value in year t.
A_t = Actual value in year t.
N = 21 for revised model and 18 for previous model.

[a] $$U = \left[\sum_{i=2}^{N} (P_i - A_i)^2\right]^{1/2} \Big/ \left[\sum_{i=2}^{N} A_i^2\right]^{1/2}$$

[b] $$MAPE = \frac{1}{N}\left[\sum_{t=1}^{N} \left|\frac{P_t - A_t}{A_t}\right|\right] \times 100$$

[c] $$MPE = \frac{1}{N}\left[\sum_{t=1}^{N} \frac{P_t - A_t}{A_t}\right] \times 100$$

The results listed in Table 3 indicate that our revised model fits the sample data well. Values near zero for each of the "goodness of fit" measures indicate a good fit to the data; and good fit over the sample period suggests that the consumption and price equations can project future levels for those variables. How well they actually perform will depend on how well we can project the independent variables and whether structural changes occur in the pallet market.

Comparison with Previous Model

In this improved version of the model, a pallet industry productivity variable is included in the supply equation, and it is assumed that the supply responses to production cost changes are lagged. We felt that the instantaneous response of pallet supply to changes in production costs assumed in the previous model was not realistic because of built-in rigidities such as labor contracts and lumber supply arrangements. After testing several lags for pallet labor and lumber costs, we adopted a 2-year moving average, lagged 1 year, because it gave the best least squares statistical fit.

Pallets per man-hour is the productivity variable selected for the revised model. Productivity measures are usually combined with the labor cost variable to give a "unit labor cost" measure because most economists feel that productivity changes influence production costs via changes in labor costs. The productivity variable is really a proxy measure of both productivity and utilization of plant capacity. A "unit labor cost" variable was tested, but it was strongly correlated with the lumber cost variable, and the lumber cost became statistically not significant. However, since lumber cost accounts for over 50 percent of pallet production cost, it was kept in the supply equation. Furthermore, there was not a significant difference in R^2 between the models with either variable.

This improved model is stronger statistically than the previous models; all variables are significant at the 7 percent level (versus 40 percent in the 1980 model). In addition, the standard errors in the revised model are consistently smaller

Table 4.—A comparison of the estimated coefficients and their associated standard errors (SE) for the revised model and the previous model developed by Schuler and Wallin (1980)

Variable	Revised model			Previous model		
	Coefficient	SE	Associated t-statistic	Coefficient	SE	Significance level of t-statistic
Demand equation						
Pallet price	– 61741	18925	3.26	– 65137	22174	0.01
Industrial production index	2914	173	16.81	3147	305	0.0001
Pallet substitute	– 97131	63866	1.53	– 126268	72912	0.10
Constant	152364	110924	1.38	181962	89000	
Supply equation						
Pallet price	428484	122515	3.50	517553	254989	0.06
Red oak lumber price	– 3055	1479	2.10	– 3464	4006	0.40
Pallet industrial labor cost	– 493492	155680	3.17	– 641145	368441	0.10
Productivity	131319	32508	4.04	NA		
Constant	– 584119	198238	2.94	– 154359	101000	

(Table 4). Consequently, we feel that the projection potential of the consumption and price equations, (3) and (4), is enhanced. A comparison of the "goodness of fit" measures in Table 3 substantiates this conclusion, particularly for the consumption equation.

The demand equation, (1), of the improved model is basically the same as the 1980 version. The same variables were used as demand shifters—pallet price, industrial production index, and pallet substitute; and the Durbin-Watson D-statistics are similar. However, the revised model does have smaller standard errors for each variable (Table 4).

Concluding Comments

This revised econometric model of the domestic pallet market is superior to the ones reported in 1979 and 1980. The structure of the supply equation, with the use of lagged relationships, is more realistic. The model incorporates the latest data. The variables are stronger in their least squares statistical fit. We believe these improvements provide equations that are better suited to projecting pallet consumption and price levels in the short term (1 to 5 years).

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- Warren, Pennsylvania.

Schuler, Albert T.; Wallin, Walter B. A revised econometric model of the domestic pallet market. Res. Pap. NE-522. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 5 p.

The purpose of this revised model is to project estimates of consumption and price of wood pallets in the short term. The model is intended to provide reliable estimates of the quantity of pallets required and their real price over a relatively short term of 1 to 5 years. It is not intended to be used in determining policy concerning the growth or decline of palletization in materials handling.

ODC 721.1

Keywords: Demand, supply, consumption, projections

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Stocking, Growth, and Habitat Relations in New Hampshire Hardwoods

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Abstract

Data from hardwood stands in New Hampshire substantiated the crown-width relationships used to develop the B-line (based on circular crowns) in the 1969 northern hardwood stocking guide, and produced an A-line slightly lower than the original line. Position of the A-line was unrelated to site or forest type. Diameter growth of hardwoods on moist and dry soils declined rapidly with increasing tree diameter. On fine till, diameter growth was nearly constant over tree diameter but positively related to relative crown size. Based on diameter-growth regressions, calculations of stand growth indicated that the minimum basal area for adequate even-aged stand growth was quite low (30 to 60 square feet) and roughly constant over mean stand diameter.

Introduction

Stocking guides for even-aged stands have been developed for many of the forest types in the East, based upon work with crown areas in upland oaks (Gingrich 1967). These guides have been widely used in both practice and research. However, recent comparisons indicate that stocking levels recommended in certain of these guides do not correspond to the stocking limits implied by published growth studies (Leak 1981). Northern hardwoods and upland oaks produced full growth per acre at basal areas up to about 20 square feet below minimum stocking (the B-line), while white pine and red pine produced full growth only at basal areas well above the B-line. Possible reasons for these discrepancies are: (1) crown-area approaches may not adequately define stocking; (2) alternative definitions of crown or tree-area shapes (square versus circular) or the acceptable range in crown class (all trees taller than 4.5 feet versus trees in the main crown canopy); (3) differences in site or species composition might affect the influence of stocking or the nature of the growth response; and (4) relationships between growth and stocking might not be evident until stands are in a fully managed condition.

This study aids our understanding of these sources of discrepancy by providing information on stocking estimates, diameter-growth, and simulated growth per acre of free-to-grow trees as related to crown dimensions and forest type/habitat combinations.

Methods

A cluster of plots of three 10-factor prism points was located in 32 even-aged hardwood stands in the southern White Mountains of New Hampshire. As defined by the habitat classes (Leak 1980) recognized in the White Mountains, the sites were: (1) fine till soils (fine till habitat), (2) moist soils (wet compact, dry compact, and silty sediment habitats), (3) dry soils (coarse and fine washed till, and sandy sediment habitats), and (4) rocky soils (shallow-to-bedrock and loose rock habitats). The forest types were typical northern hardwoods (beech/sugar maple) on the fine soils, and beech/red maple/birch on the other three soils. Average stand diameters (main canopy) ranged from 1 to 14 inches (Table 1).

On each point, all trees were recorded by species, dbh, and canopy position (main crown canopy or suppressed). In addition, 2 or 3 dominant, essentially free-to-grow sample trees were selected on or near each plot cluster. Crown widths along the major and minor axes were measured on each sample tree, using a range pole leveling bubble to vertically project the edges of the crown. Species, dbh, and distance (bole to bole) to each competitor were recorded. A competitor was a tree in the main crown canopy touching the crown of the sample tree. An increment boring over the last 10 years of growth (except on trees younger than 10 at dbh) was taken on four sides (uphill, downhill, right, and left sides) of each sample tree at dbh.

Average diameter growth inside bark (ib) per tree over each of the last two 5-year periods was determined. Predicted diameter (ib) growth over the next 5-year period was determined by linear projection of the trend from the previous two 5-year periods. However, if the projected trend was upward (rather than level or declining), predicted diameter growth was taken as the diameter growth over the last measured 5-year period. (There were a few obviously undersized rings in the earliest 5-year period.) This procedure is conservative, and tends to capture the gradual declining trend in diameter growth usually evident in free-to-grow trees. We used predicted diameter growth instead of

Table 1.—Data characteristics, main crown canopy

Forest type	Soils	Plot Clusters	Range		Percentage of species composition,[a] and no. of sample trees											
			Dbh	Trees/ acre	Sugar maple		Beech		Red maple		Yellow birth		Paper birch		Other	
		No.	*In*	*No.*	%	*No.*	%	*No.*	%	*No.*	%	*No.*	%	*No.*	%	*No.*
rthern hardwoods	Fine till	7	1.8—13.7	118—3,231	25	9	31	5	2	—	12	5	14	4	16	—
ech-Red Maple-rch	Moist	7	1.2—10.2	167—4,506	1	—	9	1	37	6	15	3	27	7	11	—
ech-Red Maple-rch	Dry	14	1.6—12.5	126—3,424	1	—	40	9	23	8	5	3	24	12	7	—
ech-Red Maple-rch	Rocky	4	7.0—9.0	187—417	4	—	29	3	31	1	9	3	11	3	16	—

[a] Percentage of species composition in terms of basal area in the main canopy.

past diameter growth because we wished to develop regressions that would be useful in predicting future growth. To do this, it is necessary either to use predicted future diameter growth or to attempt to recast the independent variables such as tree diameter, spacing, crown width, and so on.

A comparison of average past 5-year growth and future 5-year growth in diameter (ib), predicted as described above, showed a decline in growth of about 9 percent for paper birch and less for other species:

Species	*Past*	*Future*
	---- *Inches* ----	
Sugar maple	0.93	0.88
Beech	.90	.88
Yellow birch	.66	.64
Paper birch	.90	.82
Red Maple	.69	.64

In analyzing results of the study, 5-year growth in diameter (ib) was converted to diameter outside bark (ob) using double bark thickness data from New York (Belyea 1933).

Results

A-line

The upper limit of stocking in most eastern stocking guides is defined by the A-line, which is a fitted or constructed curve of basal area per acre over numbers of trees for essentially undisturbed stands. In developing the northern hardwood stocking guide (Solomon and Leak 1969), this curve was fitted to trees in the main crown canopy, but guides for certain other regions (for example, Roach 1977) emphasize the need to include all trees. A polynomial was used to fit the curve in both ways to the 32 cluster averages in this study:

$$BA(\text{all trees}) = 146.88 - 0.020963\,(\text{no. trees}) + 0.0000012\,(\text{no. trees})^2 \quad (1)$$

R = 0.73

Standard deviation = 23.3 (20.0% of mean)

$$BA(\text{main canopy}) = 116.72 - 0.027488\,(\text{no. trees}) + 0.000002219\,(\text{no. trees})^2 \quad (2)$$

R = 0.87

Standard deviation = 13.4 (13.7% of mean)

The fit was better using only the main canopy because groups of small trees occur sporadically in northern hardwood stands, causing added variation in both numbers of trees and basal area. In addition, use of all trees sometimes results in an unusually low mean stand diameter. A stand of sawtimber averaging 13 inches in the main crown canopy might have an average diameter of as little as 7 inches when all trees are measured.

Average deviations (1969 A-line minus equation 2 estimates) in basal area of the main canopy were similar for all forest type or soils classes:

Forest type	*Soils*	*Average deviation* ft^2
Northern hardwood	Fine till	+ 7.1
Beech/red maple/birch	Moist soils	+ 5.9
Beech/red maple/birch	Dry soils	+ 5.7
Beech/red maple/birch	Rocky soils	+ 7.2

Differences between the original A-line and the new data were significant (0.05 level) for all types or soils combined, based on comparisons within the range of the 1969 curve. However, the average differences are not large. The new curve tends to run lower than the original curve in the largest sizes (smaller tree numbers) only (Fig. 1).

B-line

In most eastern stocking guides, minimum stocking for full site utilization is defined by the B-line, which is a curve of basal area over number of trees. This curve is developed by defining the relationships between crown diameter and dbh of open-grown or dominant trees, calculating the area requirements of various sized trees, and finally determining the number and basal area of the trees that will fit on an acre of land.

In the present study, relationships of average crown diameter (feet) to dbh were developed for dominant trees of all five major species:

Sugar maple

$$CD = 4.9294 + 1.5548\,(dbh) \quad (3)$$
r = 0.99

Beech

$$CD = 3.9778 + 1.9948\,(dbh) \quad (4)$$
r = 0.98

Yellow birch

$$CD = 5.9087 + 1.8612\,(dbh) - 0.02545\,(dbh)^2 \quad (5)$$
R = 0.82

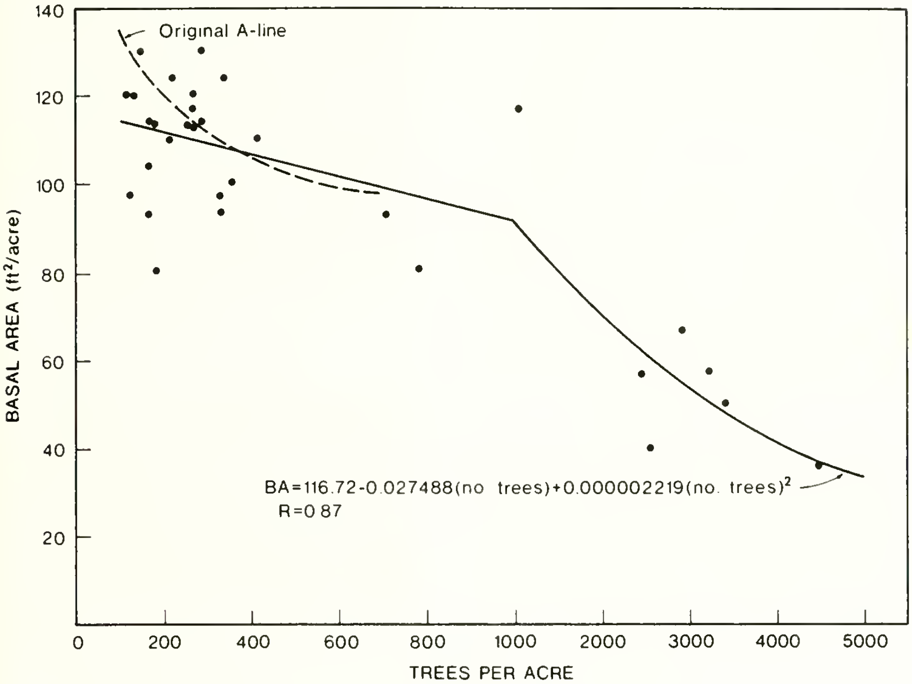
Paper birch

$$CD = 1.8194 + 2.1638\,(dbh) - 0.02328\,(dbh)^2 \quad (6)$$
R = 0.98

Red maple

$$CD = 6.9932 + 1.3900\,(dbh) \quad (7)$$
r = 0.81

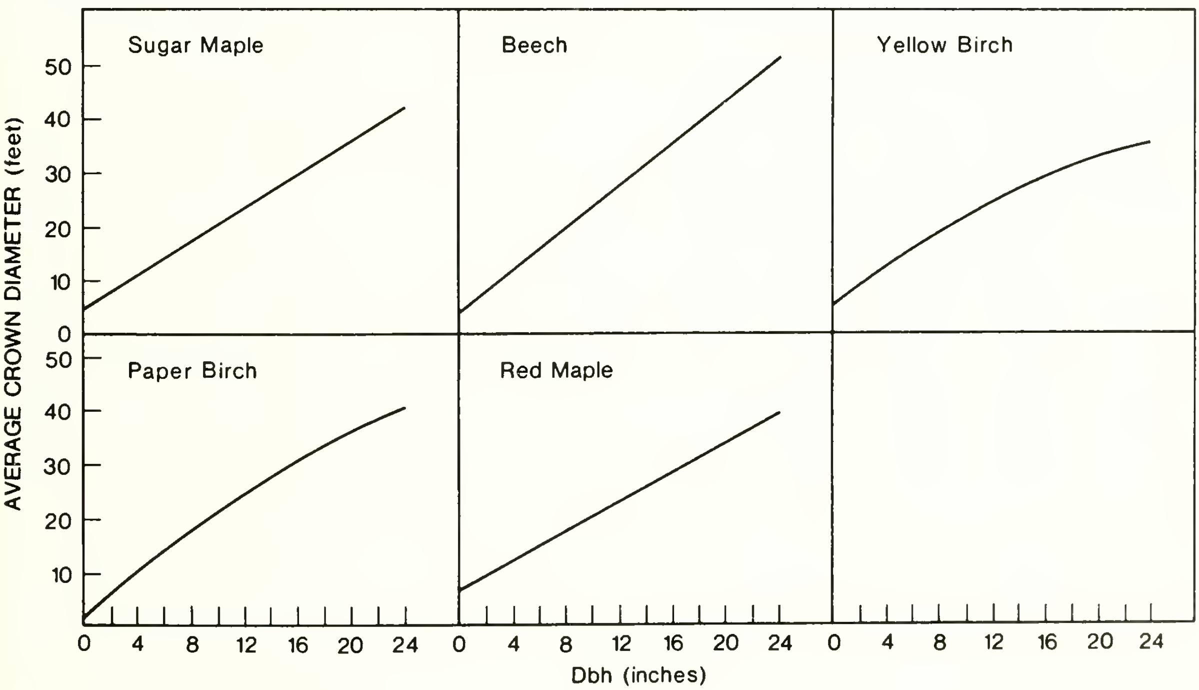
Figure 1.—Curve of basal area over number of trees for undisturbed, even-aged northern hardwoods and beech/red maple/birch. Original A-line from the northern hardwood stocking guide (Solomon and Leak 1969) is shown for comparison.



Paper and yellow birch exhibited curvilinearity in the relationship of crown diameter to dbh. Beech had the largest crowns in trees above 8 inches dbh (Fig. 2). Sugar maple, red maple, and paper birch exhibited crown diameter relationships that plotted quite closely to one another in most size classes. Plottings gave no indication that crown diameters varied with site. These crown diameter equations are similar to those summarized for other parts of New England.[1] Except for yellow birch, the New England equations provide slightly lower crown diameter estimates in medium to large trees.

[1]Solomon, D.; Schnell, J. Crown diameter—dbh relationships for commercial tree species in New England. Orono, ME: Northeastern Forest Experiment Station. Manuscript in preparation.

Figure 2.—Crown width regressed over dbh for sugar maple, beech, yellow birch, paper birch, and red maple.



By assuming either circular or square crowns (or tree areas), the number of trees and basal area per acre required by dominant or free-to-grow trees of each species were calculated (Table 2). The calculated basal areas for sugar maple, under the assumption of circular crowns; closely followed the recommended basal areas in the original 1969 B-line; other species were either lower or higher. Under the assumption of square crowns, calculated B-line basal areas for sugar maple fell 15 to 25 square feet below the original B-line. An earlier paper indicated that growth per acre of northern hardwoods and upland oaks remains high at basal areas up to about 20 square feet below recommended B-lines based on circular-crown areas (Leak 1981). Further, it is logical that crowns should be able to occupy an acre without spaces or overlap. Thus, the assumption of square-crown areas for hardwoods seems more reasonable than that of circular-crown areas.

Diameter-Growth Variability

The data from the increment borings provided the opportunity to compare rates and variability in radial growth (last 5-year period) on different sides of the tree, and to draw some conclusions on the most efficient way to sample diameter growth using increment borings.

There were no important differences in average growth among the four positions for any species. However, a few paper birch trees growing on the steepest slopes in the study area did exhibit up to 25 percent less growth on the uphill side than on the other sides.

More important, about 50 to 90 percent of the variation in diameter growth was due to variation among trees, whereas only 1 to 3 percent was due to variation among positions on the same tree. The most efficient sampling method is that which will give the most accurate estimate for a given time or cost. Because the variation among trees is large and the cost of sampling another tree is relatively small, statistical analysis[2] indicates that the most efficient way to estimate mean diameter growth from increment cores is to take one boring per tree on as many trees as time or money permit. Although differences among positions on a tree are small, except perhaps on steep slopes, I suggest taking the one core at a random position around the tree circumference to avoid consistent errors.

[2]To obtain the smallest variance for a given cost, the number of borings per tree equals $\frac{C_1}{C_2} \cdot \frac{S_2^2}{S_1^2}$, where C_1 and C_2 are the total costs of going to another tree and taking one boring, respectively, and S_1^2 and S_2^2 are the estimated variances among trees and among borings within a tree. C_1/C_2 represents the ratio between the costs of taking another tree and taking one boring per tree.

Table 2.—Calculated B-lines in basal area per acre by species for square and round crowns

Dbh	Square crowns					Circular crowns					Original 1969 B-line
	Sugar maple	Beech	Red maple	Yellow birch	Paper birch	Sugar maple	Beech	Red maple	Yellow birch	Paper birch	
	(Square feet per acre)										
2	15	15	10	10	26	19	19	13	13	33	—
4	31	27	24	23	37	39	34	31	29	47	—
6	42	34	36	33	44	54	43	46	42	56	57
8	50	38	46	41	49	64	49	59	53	62	66
10	57	42	54	49	53	72	53	69	63	68	75
12	61	44	61	57	57	78	56	78	72	73	83
14	65	46	67	64	61	83	58	85	81	78	89
16	68	47	71	71	66	87	60	91	91	83	93
18	71	48	75	79	70	90	62	96	101	89	96

Diameter-Growth Predictions

Projected 5-year diameter growth of paper birch on moist and dry soils was rapid in small trees but declined steeply as tree size became larger (Fig. 3):

5-year dbh growth (paper birch) = 1.8275 − 0.1029 (dbh) (8)

r = 0.85

Standard deviation = 0.32

Trees about 14 inches (approximately 80 to 100 years old) or larger grew very slowly, even if completely free from surrounding competition. The average deviation per tree from the regression was − 0.05 for dry soils and + 0.08 for wet soil.

Projected diameter growth of beech, red maple, and yellow birch on moist and dry soils followed a declining trend similar to paper birch, though less steep (Fig. 3):

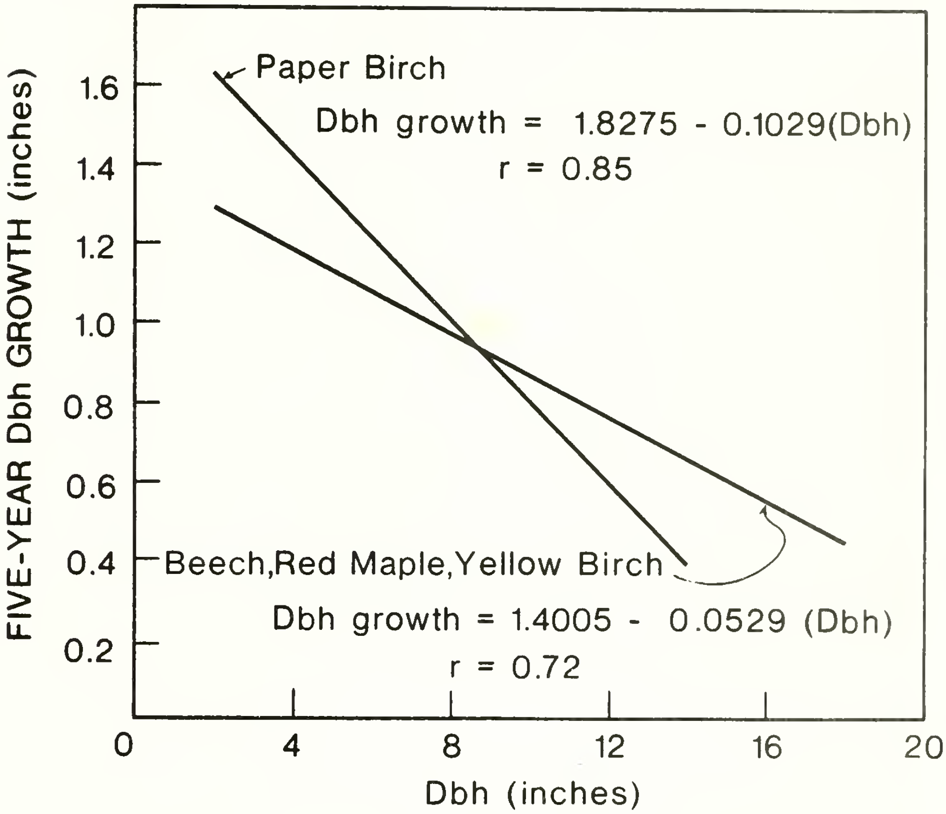
5-year dbh growth (beech, red maple, yellow birch)

= 1.4005 − 0.0529 (dbh) (9)

r = 0.72

Standard deviation = 0.24

Figure 3.—Five-year dbh growth regressed over dbh for paper birch and beech, red maple, and yellow birch on moist or dry soils.



Although differences among the three species represented in equation (9) were nonsignificant, average deviations in 5-year growth from the regression were moderate:

Beech 0.10 Yellow birch − 0.20 Red maple 0.01

Thus, red maple fell closest to the regression line, while beech grew a little faster and yellow birch somewhat slower.

Neither regression on moist or dry soils showed any relationship between growth and deviations in either crown width or spacing; this could indicate that growth responses in relation to spacing or stocking are less on these moist or dry soils than on the fine tills described next. Although it may seem unusual to have a common growth relationship for moist and dry soils, both of these site groups have a similar successional sequence: softwoods are climax, and the hardwoods (beech, red maple, and birch) are subclimax.

A different form of relationship was evident for sugar maple, beech, yellow birch, and paper birch on fine till. Here, projected 5-year diameter growth showed almost no relationship to crown size expressed as actual crown width minus predicted crown width (predicted from the appropriate crown width regression (equations 3 through 6) by species):

5-year dbh growth (sugar maple, beech, yellow birch, and paper birch) = 0.9017 + 0.0006 (dbh) + 0.0758 (Actual minus predicted crown width) (10)

R = 0.56

Standard deviation = 0.25

Although R is not large, the standard deviation is about as small as or smaller than that in the previous two equations (8 and 9). Average deviations by species from the regression were small:

Sugar maple	0.024
Beech	0.028
Yellow birch	− 0.046
Paper birch	− 0.035

Even one very large paper birch was growing well on fine till. No small paper birch were sampled; thus, the equation probably does not apply to small paper birch.

A logical question is whether larger-than-average crowns are due to inherent differences among trees, or to variations in spacing. Average spacing around each sample tree was determined by measuring distance to each main-canopy competitor (usually four competitors per sample tree). Each distance was subdivided in proportion to the diameter of the sample tree versus the diameter of the competitor. An average spacing figure[3] was calculated for each sample tree, and spacing was regressed over dbh. Finally, the correlation between actual minus predicted spacing and actual minus predicted crown width was 0.45 (significant at 0.05 level). This correlation indicates that larger crown widths are related to spacing and that the faster growth rates exhibited by larger crowned trees can be attained by increasing spacing or lowering stand density.

When figures 3 and 4 are compared, they show that hardwood diameter growth on moist and dry soils begins rapidly but tapers off quickly with size or age. However, growth is sustained up to large sizes on fine till. These growth trends probably explain why successsional hardwoods on softwood sites produce about as much standing cubic-foot volume, but less than two-thirds the board-foot volume, as northern hardwoods on fine till (Leak 1982).

Diameter growth of sample trees growing on rocky soils was extremely variable, probably because rocky soils are variable in nature. These sample trees were not used in developing growth relationships.

Calculated Growth

By repeated application of the diameter-growth equations (8, 9, and 10),[4] you can project tree size over age (Figs. 5 and 6). Projected tree sizes for dominant, free-to-grow stems of beech, red maple, yellow birch, and paper birch on moist or dry soils follow a decreasing parabolic trend. Tree size over age for northern hardwoods on fine till is essentially a straight-line relationship. The possibilities for growing larger sized trees rapidly are obviously best on fine till.

[3]For example, the bole-to-bole distances between a 16-inch sample tree and four 8-inch competitors were 20, 20, 24, and 24 feet: the average spacing figure would be calculated as: $\frac{16}{16+8}(20 + 20 + 24 + 24) \times 2 \div 4 = 29.3$ feet.

[4]Projected tree size can be represented by a difference equation:

$Y_{t+5} - Y_t = a - bY_t$
which has the solution
$Y_t = a(1 - (1 - b)^{t/5})/b$
where
Y = tree diameter
t = time in years

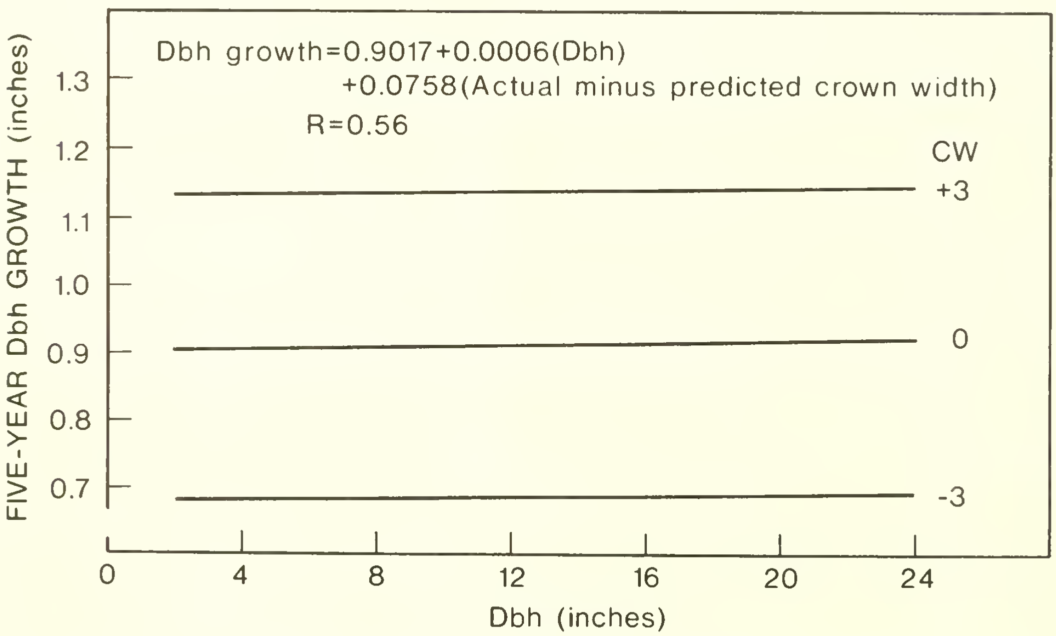


Figure 4.—Five-year dbh growth regressed over dbh and actual minus predicted crown width for sugar maple, beech, yellow birch, and paper birch on fine till.

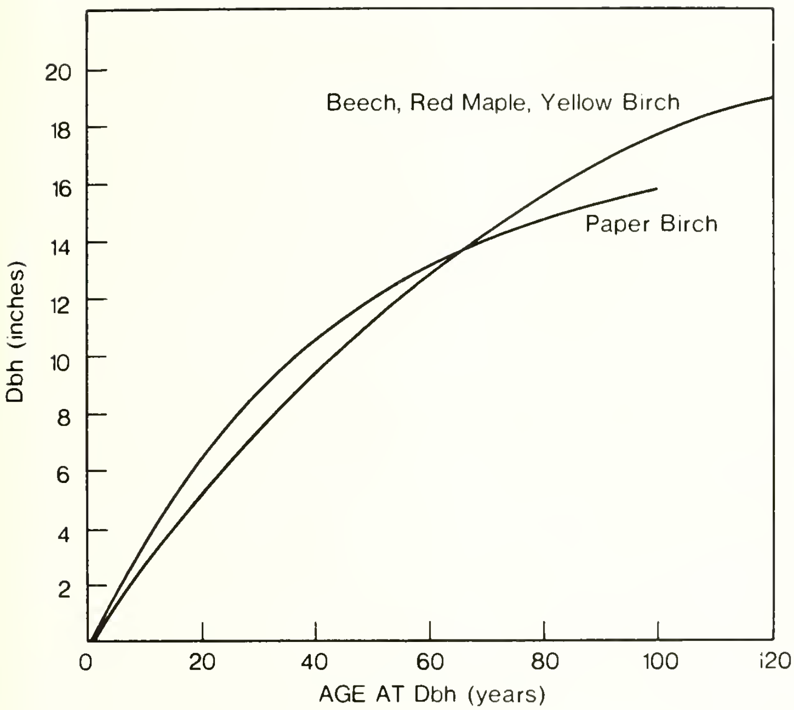


Figure 5.—Cumulative dbh over age for paper birch and beech, red maple, yellow birch on moist or dry soils simulated from regressions of 5-year diameter growth over dbh.

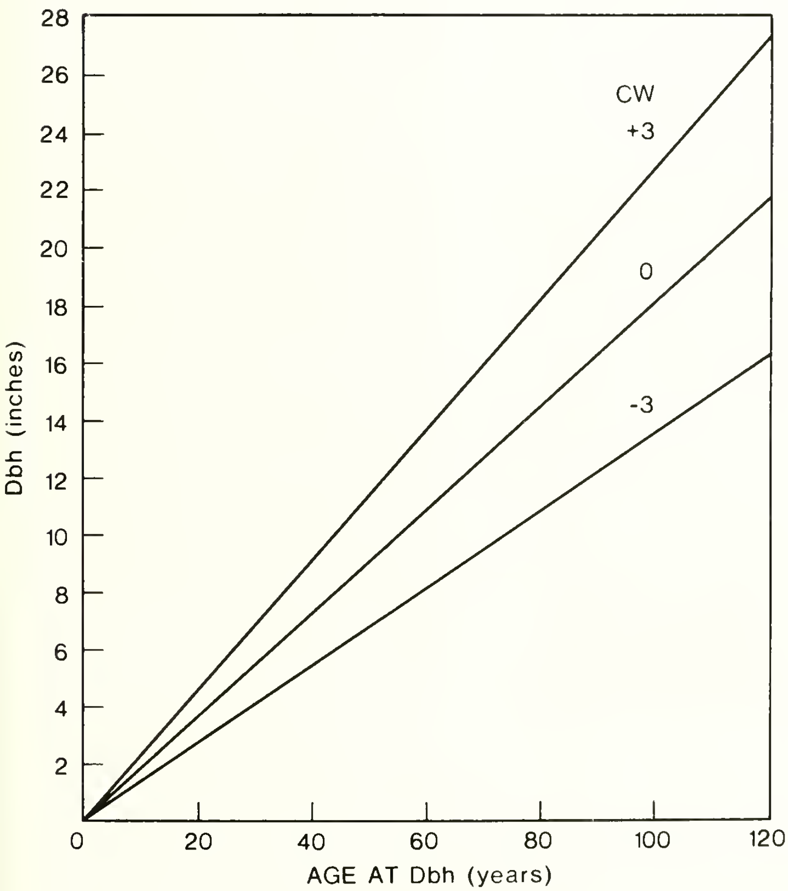


Figure 6.—Cumulative dbh over age for actual minus predicted crown widths of +3, 0, and −3 for sugar maple, beech, yellow birch, and paper birch on fine till. Simulated from regressions of 5-year dbh growth over age and actual minus predicted crown width.

Numbers of free-growing trees per acre (B-line) can be estimated under assumption of either square or circular crowns by using crown-width relationships (equations 3 through 7). By applying the appropriate diameter-growth equation (8, 9, or 10) and calculating change in basal area, you can calculate basal-area growth per acre for stands at the B-line. These growth figures represent survivor growth on dominant crop trees, without losses to mortality or additions from ingrowth. Growth in basal area and cubic volume are quite well correlated in northern hardwoods.

On the basis of square crowns, annual growth in basal area per acre was calculated for stands of the major species on both moist and dry soils (Table 3) and fine till (Table 4). The growth figures represent well-managed, even-aged stands at the low residual densities calculated from square crowns. If growth had been calculated under the assumption of circular crowns, the growth figures (Table 3 and 4) and residual basal areas (Tables 2 and 5) would be multiplied by 1.27. Calculated growth figures are fairly close to published data. Stands of mixed hardwoods on moist and dry soils averaging about 9 to 10 inches dbh (main canopy), cut to a range of residual densities, produced accretion figures of 1.7 to 2.0 square feet (Solomon 1977). A young stand of northern hardwoods on fine till, with a mean stand diameter of 3.5 to 4 inches in the main canopy, produced net growth of 4.0 square feet for the entire stand and 3.2 square feet for the sample trees alone following heavy thinning (Marquis 1969).

The influence of various stand densities on growth per acre is reflected by the growth calculations for fine till (Table 4) and the corresponding table of residual basal areas (Table 5). For example, calculated annual growth per acre for a 4-inch sugar maple stand is 4.20 square feet (Table 4) when the crowns average 3 feet (– 3 feet) below predicted, and the trend in growth per acre apparently is decreasing as the crowns get smaller. Table 5 shows that a 4-inch sugar maple stand with a – 3-foot average crown corresponds to 57 square feet of basal area per acre. A 12-inch sugar maple stand produces about the same basal-area growth (1.88 to 1.93 square feet) over all average crown widths (Table 4), or at any basal area between 48 and 81 square feet per acre (Table 5). If you use this approach, minimum basal area for nearly maximum growth per acre of sugar maple, beech, and yellow birch is approximately:

Dbh	*Sugar maple*	*Beech*	*Yellow birch*
		ft²	
4	57+	47+	38+
6	67+	51+	49+
8	37-74	29-53	41-58
10	43	33	38
12	48	36	45
14	53	38	52
16	56	40	59
18	60	42	66

This tabulation of minimum residual basal area corresponds reasonably well with the published record. In the 25-year-old northern hardwood stand previously mentioned, averaging about 3.5 to 4 inches in the main crown canopy, a heavy thinning to 56 square feet total basal area (with 31 square feet in sample trees) produced better net stand growth per acre than a light thinning to 72 square feet (with 33.5 square feet in sample trees). Growth on sample trees alone, which accounted for about 80 percent of the stand growth, also was best following the heavy thinning. In mixed northern hardwoods (beech/red maple/birch) averaging about 9 to 10 inches in the main canopy, accretion was best at 60 square feet (50 to 55 square feet in the main canopy) residual density. Accretion at 40 square feet (30 to 35 square feet in the main canopy) residual density was only 7 percent less. Keep in mind that these studies were in previously unmanaged (untreated) stands. Under intensive management, crown development per tree and spacing would be better, which would tend to allow fewer trees (lower basal areas) to occupy a site.

This tabulation also illustrates that minimum basal area for full growth per acre apparently does not increase markedly with increasing stand size or age; the trend varies among species from roughly constant to slightly rising to concave in shape. The data are too limited to reveal trends for various species mixtures. Eastern stocking guides all show that minimum stocking (B-line) increases consistently with increasing stand size or age. However, well-designed growth studies in hardwoods tend to support the view that minimum basal area remains more-or-less constant over age and presumably size as well. Optimum residual density for basal-area growth of upland oaks ranges from only 40 to 50 square feet for stands ranging in age from 20 to 110 years (Dale 1972). A similar trend is evident for yellow-poplar (Beck and Della-Bianca 1972). For example, on an average site (SI = 110), peak basal-area growth of yellow-poplar is attained (with only two minor exceptions) at residual basal areas of 80 to 90 square feet for stands ranging in age from 20 to 80 years. In this study, the basal-area growth was very flat over a broad range in residual density. If minimum basal area is constant over age, then the optimum residual stocking percent (B-line basal area as a percentage of A-line basal area) will decrease markedly as the stands get older or larger.

Table 3.—Projected annual growth per acre on moist and dry soils in basal area by species and mean stand dbh

Stand Dbh	Beech	Yellow birch	Paper birch	Red maple
4	3.63	3.10	6.21	3.30
6	2.65	2.58	3.90	2.87
8	1.98	2.15	2.61	2.40
10	1.51	1.79	1.77	1.98
12	1.16	1.49	1.16	1.61
14	.88	1.24	.69	1.29
16	.67	1.01	.30	1.00
18	.49	.80	—	.76

Table 4.—Projected annual growth per acre on fine till in basal area by mean dbh, species, and actual minus predicted crown widths of +3, 0, and −3 feet

Dbh	Sugar maple			Beech			Yellow birch		
	+3	0	−3	+3	0	−3	+3	0	−3
	Square feet								
4	2.45	3.08	4.20	2.19	2.67	3.47	1.93	2.28	2.82
6	2.37	2.73	3.22	1.97	2.18	2.44	1.92	2.13	2.36
8	2.22	2.41	2.61	1.75	1.83	1.88	1.88	1.98	2.06
10	2.07	2.15	2.19	1.57	1.57	1.53	1.83	1.87	1.85
12	1.92	1.93	1.88	1.42	1.38	1.29	1.78	1.78	1.72
14	1.78	1.75	1.65	1.29	1.23	1.11	1.75	1.72	1.62
16	1.66	1.60	1.48	1.18	1.11	.98	1.73	1.67	1.55
18	1.56	1.48	1.33	1.09	1.01	.88	1.72	1.65	1.51

Table 5.—Basal areas per acre by mean dbh, species, and actual minus predicted crown widths of +3, 0, and −3 feet

Dbh	Sugar maple			Beech			Yellow birch		
	+3	0	−3	+3	0	−3	+3	0	−3
	Square feet								
2	8	15	37	8	15	38	6	10	22
4	19	31	57	17	27	47	15	23	38
6	29	42	67	24	34	51	23	33	49
8	37	50	74	29	38	53	31	41	58
10	43	57	78	33	42	54	38	49	66
12	48	61	81	36	44	55	45	57	73
14	53	65	83	38	46	56	52	64	81
16	56	68	85	40	47	56	59	71	89
18	60	71	86	42	48	57	66	79	97
20	62	73	87	43	49	57	74	88	106
22	65	75	88	44	50	57	82	96	116
24	67	77	89	45	51	57	90	106	126
26	69	78	90	46	52	58	100	117	138

Quality

Quality was subjectively rated on the sample trees used to develop crown and growth relationships in this study. Only 35 to 40 percent of the beech and sugar maple were judged good or adequate in terms of form or clear boles, while over 80 percent of the red maple and paper birch and 60 percent of the yellow birch fell in these categories. The quality evaluation was not precise, but it indicates that quality of sugar maple, beech, and yellow birch could be an important problem if grown at the minimum densities indicated in tables 2 and 5. If grown at such low densities, to preserve quality take steps such as pruning or providing adequate trainers in the suppressed- and intermediate-crown classes, especially until the trees develop acceptable clear lengths. Marking guides for low-density management will need to recognize species differences in quality potential and the need to maintain trainers.

Conclusions

Results from this study confirmed the accuracy of the crown-width relationships used to develop the B-line (based on circular tree areas) in the northern hardwood stocking guide, and indicated that the A-line might be lowered for the larger stand diameters. Crown widths, or the resultant B-lines, did not vary with site; however, because certain species have appreciably wider or narrower crowns than others, it is possible that B-lines would vary with hardwood species composition. The A-line did not vary with site or hardwood forest type. An A-line regression based on trees in the main crown canopy was less variable than one based on all trees in the stand.

Simulated growth results and published growth information indicate that the minimum basal area for maximum growth is quite low (30 to 60 square feet) and roughly constant with increasing stand diameter. Thus, stocking guides based on crown area, which produces an increasing trend in minimum basal area over stand diameter, may not accurately define minimum required stand densities.

Diameter growth of dominant beech/red maple/birch trees on moist or dry soils declined sharply with increasing tree diameter. Hardwood diameter growth on fine till, however, was nearly constant over tree size and related to relative crown size. Calculations indicated that well-spaced hardwoods on fine till at age 100 could be up to 7 inches larger than beech, red maple, yellow birch, or paper birch on moist or dry soils. In growing trees at low densities, however, stem quality will be a problem with sugar maple, beech, and perhaps yellow birch. Artificial pruning or the maintenance of suppressed or intermediate trainers will be necessary at least until sufficient clear length is developed.

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Data from hardwood stands in New Hampshire substantiated the crown-width relationships used to develop the B-line (based on circular crowns) in the 1969 northern hardwood stocking guide, and produced an A-line slightly lower than the original line. Position of the A-line was unrelated to site or forest type. Diameter growth of hardwoods on moist and dry soils declined rapidly with increasing tree diameter. On fine till, diameter growth was nearly constant over tree diameter but positively related to relative crown size. Based on diameter-growth regressions, calculations of stand growth indicated that the minimum basal area for adequate even-aged stand growth was quite low (30 to 60 square feet) and roughly constant over mean stand diameter.

Keywords: Stocking, growth, habitat, site, northern hardwoods

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Conventional Processing of Standard-Size Edge-Glued Blanks for Furniture and Cabinet Parts: a Feasibility Study

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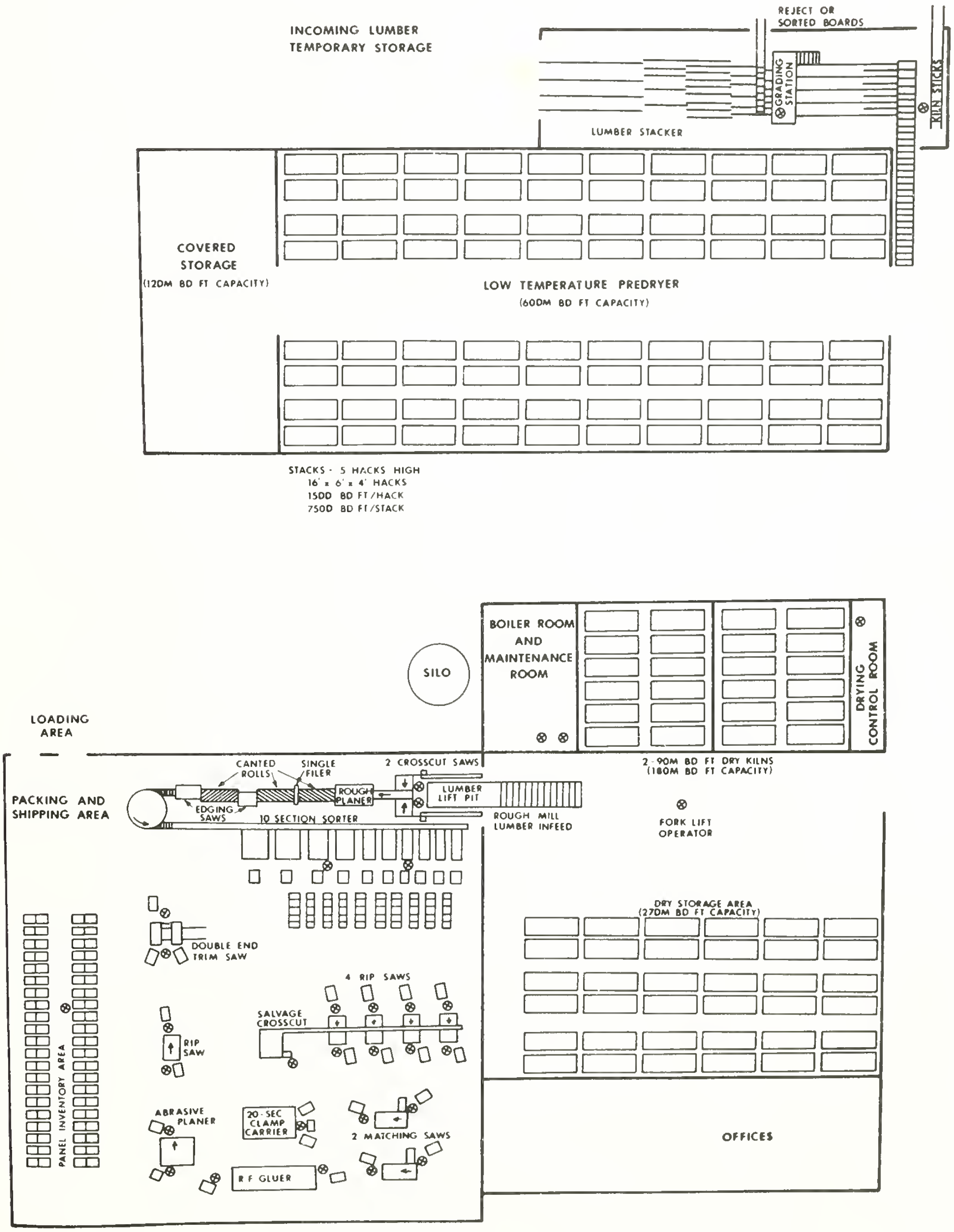
and Bruce G. Hansen



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Abstract

Manufacturers of furniture and cabinets use more than 2 billion board feet of hardwood lumber annually. As demand intensifies, we will need to utilize more of the abundant lower grade hardwood resource to assure future supplies at reasonable prices. Conventional processing of standard-size hardwood blanks manufactured from log-run red oak lumber, a resource containing over 40-percent low-grade No. 2 Common lumber, has been shown to be technically and economically feasible. Internal rates of return from 26 to 40 percent are possible when blanks are produced for outside sales or to replace open-market purchases of dimension. Accounting-based costs of producing 4/4 and 5/4 red oak blanks for internal consumption range from about $0.89 to $1.07 per square foot.

Introduction

In normal times, manufacturers of furniture and cabinets use more than 2 billion board feet of hardwood lumber, or about one-third of all hardwood lumber demanded, each year. Although the market for hardwood lumber currently reflects the overall economic downturn, once things improve the competition for our limited better grade resources will intensify. We will need to use more of the abundant lower grade hardwood resource to assure adequate supplies at reasonable prices.

A breakthrough toward this end was development of the standard-size blanks concept (Araman et al. 1982; Araman 1982), which focuses on the commonality in parts requirements among furniture and cabinet manufacturers. It was found that nearly all of the thousands of individual dimension part sizes used by the industry could be obtained from as few as a dozen sizes of blanks (wide edge-glued panels) in each required thickness. Conventional processing of low-grade lumber directly into rough dimension cuttings is considered difficult, if not impossible, by many. But making standard edge-glued blanks and processing them into rough dimension cuttings does hold promise because when the blanks are made:

- up to 12 standard lengths can be cut at one time with a longest-length-first cut-off technique,
- random-width cuttings can be edge-glued into wide blanks, and
- flexible inventories of blanks can be maintained and costly rough mill undercutting or overcutting problems can be eliminated.

To evaluate the potential of producing blanks from log-run lumber (No. 2 Common and Better), we simulated the operation of a modern, conventionally equipped plant to process 16 Mbf (thousand board feet) of lumber into 9.6 Mbf of edge-glued blanks per shift. In this report we will evaluate the economics of producing blanks for outside sales and for internal use within a parent company. In both situations we assume the production of 70 percent 4/4 and 30 percent 5/4 clear red oak blanks. For outside sales we assume that a totally new plant costing nearly $3 million will be required and that the blanks will sell for a weighted average price of $1.80 per square foot (90 percent of current dimension market values). These analyses focus upon calculation of the standard discount cash flow internal rate of return (IRR) and net present value (NPV) investment performance measures. For internal use, we based our analyses on accounting costs so as to facilitate more direct comparison with existing industry data. Since those contemplating a switch to blanks may make use of existing plant and equipment, we allowed for different amounts of capital investment in our analyses.

Our analyses indicate that investment in a new plant and equipment for open-market sales should result in an after-tax IRR of more than 26 percent if the plant is operated one shift per day. If it were operated two shifts, an IRR of almost 40 percent could be achieved. For those choosing internal use of the blanks, the cost per square foot of blanks manufactured ranges from $0.89 to $1.07 depending on the amount of new capital investment required and the level of operation. We believe that these costs are generally lower than those incurred by furniture manufacturers. As a result, conventional processing of standard-size blanks would seem to make economic sense regardless of whether they are produced for sale or for internal use.

Raw Materials and Product Yield

The raw material used to produce the standard-size blanks is assumed to consist of 70 percent 4/4 and 30 percent 5/4 green log-run red oak lumber purchased from local mills. We assume that the grade mix of this material is similar to that reported by Vaughan et al. (1966) for log-run upland red oak. If so, it contains 9 percent FAS (First and Seconds), 5 percent Select, 45 percent No. 1 Common, and 41 percent No. 2 Common. The lumber input cost of $293 per Mbf reflects a weighted average of the market prices for the different grades for both 4/4 and 5/4 red oak lumber as reported in Abe Lemsky's Hardwood Market Report (1981). A $40 delivery charge is added to each Mbf bringing the total input cost to $333 per Mbf.

Blank yields are estimated by combining the following:

- log-run grade mix,
- blank sizes and frequencies necessary to meet solid furniture dimension requirements (Table 1), and
- dimension yield tables found in Research Paper FPL-118 (Englerth and Schumann 1966).

Table 1.—4/4 clear quality standard sizes and estimated requirements for solid furniture[a]

Standard sizes L × W	Estimated requirements
Inches	%
15 × 26	6.3
18 × 26	9.7
21 × 26	9.8
25 × 26	9.8
29 × 26	9.7
33 × 26	10.4
38 × 26	9.9
45 × 26	13.3
50 × 26	2.7
60 × 26	7.2
75 × 26	6.5
100 × 26	4.7

[a]Based on data from Araman et al. (1982).

After 6 percent of the purchased input volume was deducted to account for shrinkage, the yield in blanks from the log-run lumber is 62.5 percent. To be conservative, we reduced this yield by 2.5 percentage points to 60 percent. This yield is possible partly because drying defects that normally reduce yield are minimized by predrying and then kiln drying, and by keeping the lumber protected at all times.

Processing System

The facility for producing hardwood blanks that we used in our economic analyses is illustrated in Figure 1. Although other designs are possible, ours relies on conventional techniques, including crosscutting first followed by random-width ripping. The plant site requires approximately 8 acres, and should be close to suppliers of hardwood lumber.

The mill operates 240 days per year, processing 16 Mbf of lumber into 9.6 Mbf of blanks per shift. One shift requires 3,840 Mbf of lumber annually; two shifts require 7,680 Mbf annually.

If operated on one shift, the mill employs a total of 38 people. Of these, five are classified as administrative and management. Production workers average $6 per hour, which includes a paid 2-week vacation. A second shift requires an additional management staff of two plus 29 additional production workers.

Lumber is purchased green, then graded, stacked, predried, kiln-dried, and stored for cut-up in the rough mill. Lumber is made into edge-glued panels by a conventional crosscut-rip-salvage rough mill. After edge gluing, blanks are rough planed and placed in inventory. Blanks are sold in standard sizes, but equipment is available to remanufacture the blanks to specific size parts if needed. Details of the major aspects of the production process follow.

Grading and Stacking

Incoming lumber is received and dead-piled near the lumber grading and stacking building. It is then graded and box-pile stacked automatically into hacks 16 feet long by 6 feet wide by 4 feet high, containing approximately 1,500 board feet each. Boards lower than No. 2 Common are not accepted and are stacked for the sawmiller to take back to his sawmill. Payment is based on the grade mix tally. Hacks are moved by forklift into the predrier.

Predrier

Predrier capacity is 600 Mbf of box-piled lumber. Each stack in the drier contains five 1,500-board-foot hacks. Lumber is continuously cycled through the drier. At 20-percent moisture content, the lumber is removed and placed in a covered temporary storage area before kiln drying. More than 9,000 Mbf can be processed annually, which provides excess capacity to allow for possible drying problems or delays. Average time in the predrier is 22 days.

Dry Kilns

Two 90 Mbf package dry kilns dry the lumber to 5- to 7-percent moisture content. These kilns have the capacity to dry more than 10,000 Mbf of lumber per year. Like the predrier, they provide excess capacity. Average time in the kilns is 6 days per charge.

Dry Storage

An area for dry storage and inventory for 270 Mbf of lumber is available. Here the lumber cools down after drying and is maintained at its new moisture content. Lumber stored here provides a buffer of raw material should one of the driers break down.

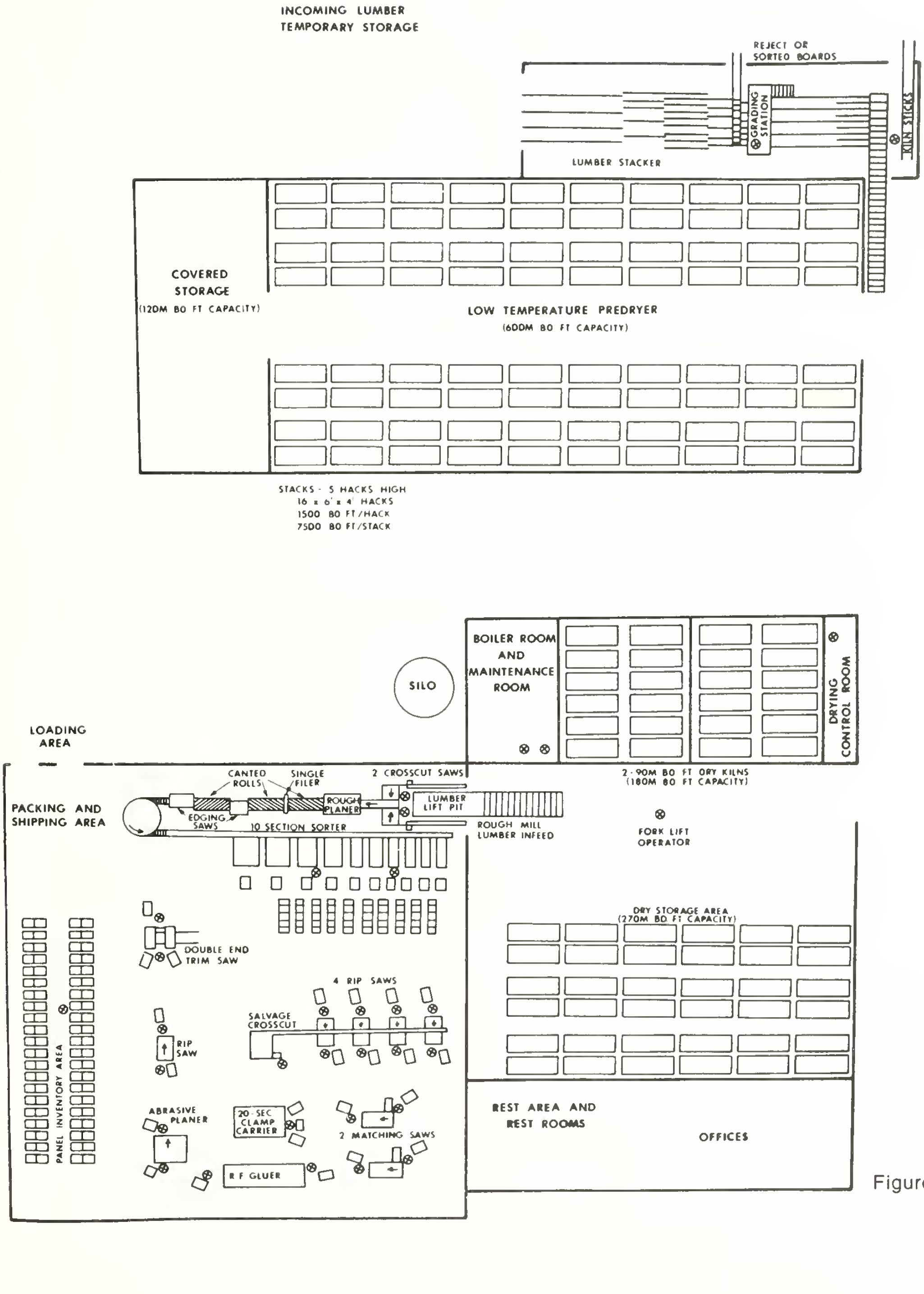


Figure 1.—Plant layout.

Rough Mill

The rough mill system can process 16 Mbf of lumber per shift into approximately 9.6 Mbf in standard-size edge-glued blanks. Hacks of lumber are rolled from the dry storage area into a lift pit in the rough mill. The lumber is then crosscut, the longest length obtainable first. Here lumber is cut into any of 12 standard lengths. Back gages are used only for the shortest three or four standard lengths. Cut-to-length boards are skip planed on two sides and automatically sent through two glue line edging saws. Boards are automatically sorted to length on a 10-section sorter and temporarily stored before ripping. Random-width cuttings are ripped from the cut-to-length boards. Pieces containing defects are salvage crosscut into shorter standard length cuttings. Clearcuttings are matched for color and grain into panel sets. Panel sets are cut to the standard blank width and edge-glued in the RF (radio frequency) gluer or the clamp carrier (either gluing system can be used). After a 24-hour period to allow for proper glue bonding, blanks are abrasive planed to 7/8 inch for 4/4 stock and 1-1/8 inches for 5/4 stock and placed in inventory on rolled conveyors.

Blanks Inventory

The inventory area is large enough for approximately 100 Mbf in blanks; an amount equivalent to the production of about ten 8-hour shifts. Inventories should be maintained to minimize the combined cost of stock-outs and holding. Actual inventory levels will depend on individual circumstances.

Filling Orders

Groups of standard-size blanks are strapped and wrapped for shipping. Specific rough dimension part orders can be filled by remanufacturing blanks into the required parts using a ripsaw and double end trimsaw located in this work area. These parts are also strapped and wrapped before shipping. Leftover edging strips from the ripping operation are recycled into the blank production at the matching saws.

Economics

Our analyses of the manufacture of hardwood blanks focus on the IRR and NPV discounted cash flow measures of investment performance. Such measures are preferred among financial analysts because they best account for the relationship among cash flows (that is, initial investment, operating cost, and revenues) throughout the life of the investment and explicitly recognize the timing of cash flows, foregone opportunities, and capital costs.

The information provided in these analyses should be of particular interest to potential investors in blanks, either for sale in the open market or to replace open-market purchases of dimension. In both instances, the price of blanks provides a good approximation of the returns (revenues, savings) that might be expected. Our assumption also provides a good approximation of the initial investment that would be required. We assume an initial investment of nearly $3 million in completely new plant and equipment (building and equipment requirements and cost estimates are found in the Appendix). Revenues are based on an average market price for blanks of $1.80 per square foot.

Open-market price and new investment assumptions may not be wholly appropriate for those furniture and cabinet manufacturers who currently produce their own dimension. The advantages blanks may hold for these investors include decreased costs; reduced production delays because of the ready availability of blanks in inventory; increased utilization of lower grade material; and consolidation of scattered rough-mill activities under one roof. Unfortunately, the economic advantages to this group are less easily identified through the IRR and NPV. First, open-market prices and internal costs are sometimes difficult to compare. Second, the initial investment required of these manufacturers is less if existing plant and equipment can be converted to the manufacture of blanks or sold. Recognizing these problems, we have developed an accounting-based cost summary that puts the information in a form comparable to existing accounting data maintained by the industry.

IRR and NPV Analyses: Data, Assumptions, and Results

Table 2 summarizes the cash flows expected during the 10-year investment in blanks manufacture for both the one- and two-shift levels of operation. Revenues and operating costs reflect a phasing-in period before full production is reached. For the single-shift operation, full production is not achieved until the second year. For the two-shift operation, full production is not achieved until the third year. More detail on how the operating costs and revenue were derived is found in Tables 3 through 6. The phasing-in of production is assumed so as to allow for training of the work force, development of the market, and other start-up adjustments that may be necessary.

Table 2.—Estimated cash flows (in thousands of dollars)

Year	Revenues	Operating costs	Depreciation[a]	Taxes[b]	After-tax[c] earnings
			One shift (full production in second year)		
1	1957	1347	329	129	481[d]
2	3914	2230	492	548	1135
3	3914	2230	464	561	1122
4	3914	2230	435	574	1109
5	3914	2230	423	580	1104
6	3914	2230	83	736	947
7	3914	2230	71	742	942
8	3914	2230	71	742	942
9	3914	2230	71	742	942
10	3914	2230	60	747	937[e]
			Two shifts (full production in third year)		
1	1957	1347	329	129	481[d]
2	3914	2230	492	548	1135[d]
3	7828	4231	464	1441	2156
4	7828	4231	435	1455	2143
5	7828	4231	423	1460	2137
6	7828	4231	83	1616	1981
7	7828	4231	71	1622	1975
8	7828	4231	71	1622	1975
9	7828	4231	71	1622	1975
10	7828	4231	60	1627	1970[e]

[a]Depreciation is based on Accelerated Cost Recovery System percentages for property placed in service between 1981 and 1984.
[b]Income is taxed at 46 percent.
[c]After-tax earnings = after-tax profit + depreciation.
[d]Actual net cash flows will be less because of additions made to working capital.
[e]Actual net cash flows are larger because of a return of working capital and assumed sale of assets at book value.

Depreciation allowances have been calculated using the Accelerated Cost Recovery System schedules provided in the Economic Recovery Tax Act of 1981. With the exception of 40 factory trucks depreciated at 3 years, equipment is fully depreciated in 5 years. Buildings and permanent fixtures are depreciated over 15 years using the schedule for real property placed in service during the sixth month of the tax year. In keeping with standard practice, assets not fully depreciated in 10 years are assumed sold at the end of the 10th year at a price equal to their remaining undepreciated value. The proceeds of these assets, plus revenue from the sale of land and the return of working capital outlays are added to the after-tax cash flows in year 10.

Taxes were computed at the Federal corporate maximum rate of 46 percent. The investment tax credit, although available, was not considered.

The initial investment comprises land, building, equipment, and related expenditures of $2,911,610 plus $255,000 in working capital to cover first-year raw material, in-process, and finished goods inventories, and sales on account. Another $160,500 is added to working capital at the beginning of the second year to cover enlarged inventories required to accompany the move to full single-shift production. These additions are deducted from the after-tax cash flow in year 1. For the two-shift option, another addition of $368,500 is made to working capital at the beginning of year 3 to provide additional inventories to support the operation of two full shifts. This addition is obtained from the after-tax cash flow in year 2.

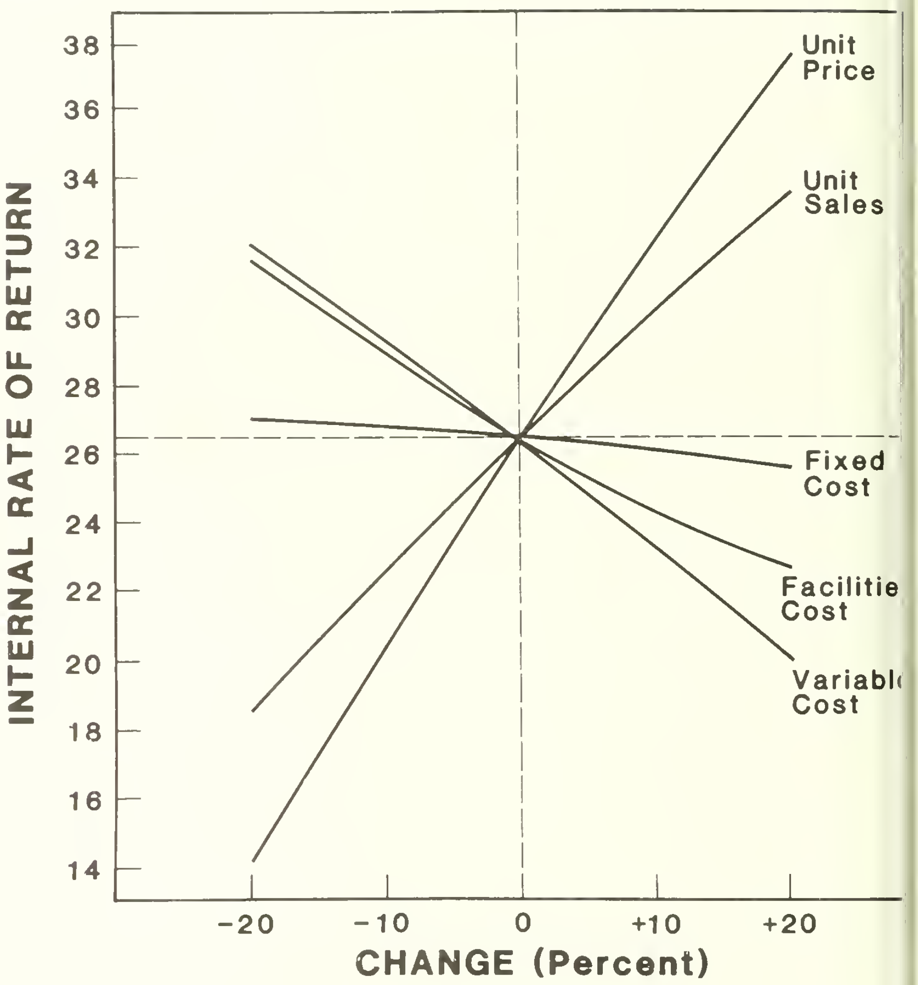
While individual investor circumstances, the cost of capital, and other investment opportunities will dictate ultimate investment decisions, it would seem from our analyses that manufacturing blanks is indeed worthy of consideration. The IRR of the one-shift operation was found to be 26.1 percent. The NPV for this same level of operation, given a 15 percent rate of discount, was $1,667,075. For the two-shift operation, the IRR was 39.8 percent; the NPV was $4,985,732.

In developing these measures, costs and revenues assumed during the 10-year period were held constant. This was done to eliminate the seemingly positive effect inflation assumptions can sometimes have on investment performance. It is realistic, in light of the history of the last decade, to expect inflationary increases. However, if misspecified, these increases can erroneously impact investment performance. For instance, had we assumed an 8-percent annual increase in both costs and revenues, the IRR for the single-shift operation would have increased to 31.8 percent; for the two-shift operation it would have increased to 46.3 percent. Under our conservative scenario of constant costs and revenues, actual performance will prove to be as good or better if inflation continues, except where costs increase at a significantly higher rate than revenues causing after-tax cash flows to decline.

The sensitivity of the IRR to changes in several investment parameters was analyzed using Harpole's cash flow analysis computer program (Harpole 1978). As can be seen in Figures 2 and 3, an increase in sales or price will increase the IRR while an increase in unit variable cost, total fixed cost, or facilities will decrease the IRR. Decreases in these factors will have a reverse effect.

The performance of both levels of operation, as measured by the IRR, is most sensitive to changes in the unit price of blanks. If the price of blanks were to drop by 10 percent from the price used in the original analysis, the IRR of the single-shift option would fall from 26.1 to 20.2 percent. A 20-percent price reduction would result in a 13.8 percent IRR, making the investment less than marginally attractive if weighed against our estimate of the cost of capital (15 percent). For the two-shift operation, the IRR would fall from 39.8 to 32.8 percent and 25.0 percent for a 10- and 20-percent drop in blank prices, respectively.

Figure 2.—IRR sensitivity to changes in selected investment parameters (single-shift operation).



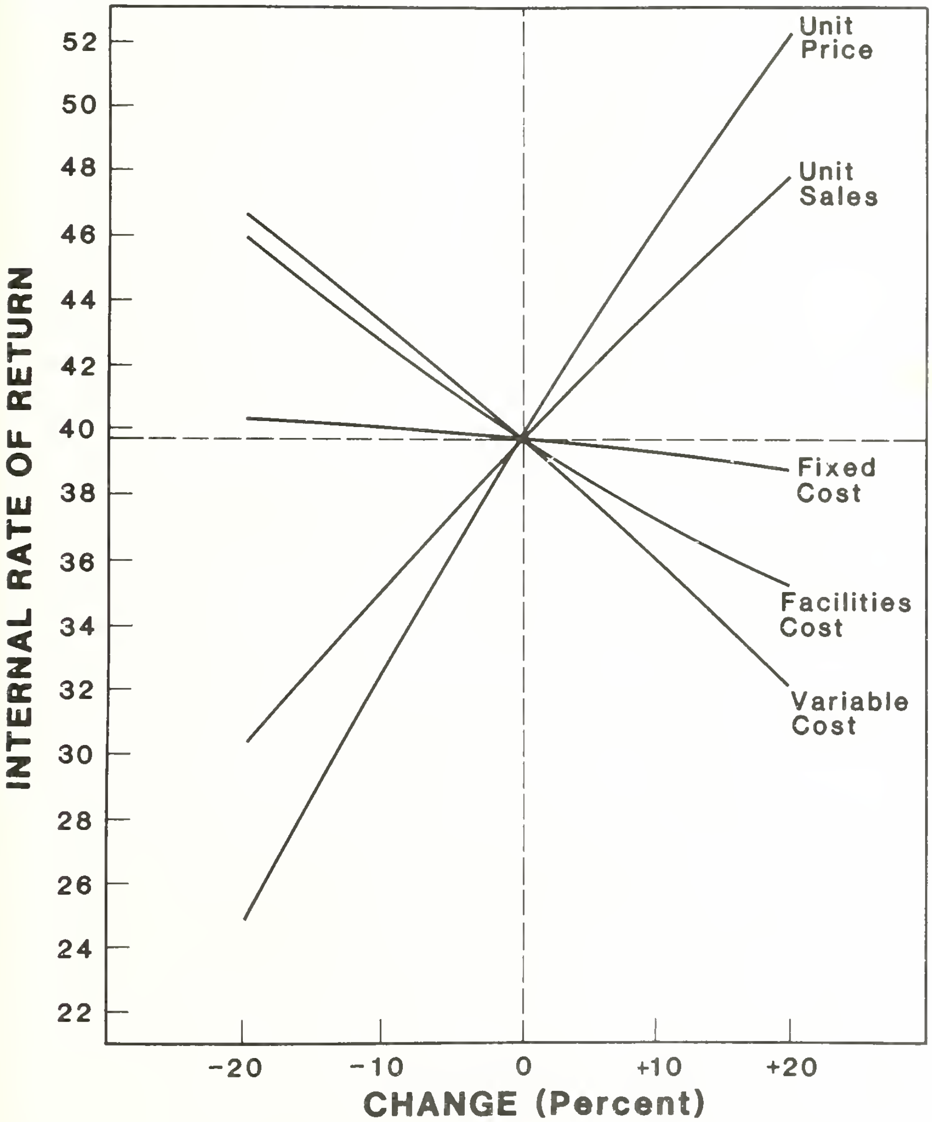
The investment is least affected by changes in total fixed costs. For both one- and two-shift alternatives, fixed cost increases of even 20 percent would reduce the IRR by less than 1 percentage point.

Accounting-Based Cost Analyses: Data, Assumptions, and Results

In developing accounting-based costs, we estimated the costs that would be incurred during a single year at full production for both the single and double shift operations. Except for the exclusion of selling expenses, the data for fixed and variable operating costs are basically the same as those found in Tables 3 and 5. Tables 4 and 6 show annual revenues for one-shift and two-shift operations.

Table 7 itemizes operating costs on a total and square-foot-of-output basis for both the one- and two-shift operations. As can be seen, total operating costs are equal to about $0.94 per square foot for the one-shift operation and about $0.89 per square foot for the two-shift operation.

Figure 3.—IRR sensitivity to changes in selected investment parameters (two-shift operation).



Investment in buildings and equipment is accounted for in Table 8. Comparison between the costs of plants established several years ago and those being contemplated today is not possible, however, unless some adjustment is made to either bring past costs in line with today's costs or to express today's costs in terms of yesterday's dollar. Therefore, to make comparisons possible, five levels of investment equal to 0, 25, 50, 75, and 100 percent of that required for a complete new facility are provided for by depreciation computed on a 10-year straight-line basis. The five levels were developed for two reasons: First, building and equipment costs for existing manufacturers are estimated by depreciation of assets placed in service several years ago. Since the early to mid-1970's, the cost of these assets has about doubled. For instance, to equate current cost estimates with those for a dimension plant placed in service during the mid-1970's, the total cost estimate using a 50-percent capital investment would likely be most appropriate. Such costs are approximately $1.00 for the one-shift operation and $0.92 for the two-shift operation. For investments made during the latter 1970's, the category representing a 75-percent commitment is probably more fitting. For comparison with investments made before the early 1970's, a zero or 25-percent commitment assumption is likely to be most suitable.

The second reason for the five divisions in building and equipment depreciation is to allow, where possible, for conversion of existing plant and equipment to blanks manufacturing, and for the sale of existing plant and equipment that is no longer useful. Regardless of the situation, the amount of new investment required will be less than that required for a complete new facility. Where such reductions are possible, the data in Table 8 will provide an indication of costs based on actual expenditures.

Inclusion of depreciation based on an expenditure equal to that required for complete new facilities increases the cost per square foot for the single-shift operation by about $0.13 and for two shifts by about $0.065. Even with these additions, the total costs per square foot should be lower than the current costs of those who manufacture their own furniture dimension.

Table 3.—Annual operating expenses, one-shift operation

Item	Year 1	Years 2–10
Variable manufacturing costs:		
Lumber		
Red oak 4/4	$ 441,788	$ 883,575
Red oak 5/4	195,075	390,150
Supplies	30,000	50,000
Labor	297,000	396,000
Utilities	40,000	60,000
Selling expenses	97,850	195,700
Fixed costs:		
Management and administrative	130,000	130,000
Insurance	70,000	70,000
Maintenance	45,000	55,000
Total operating expenses	$1,346,713	$2,230,425

Table 4.—Annual revenues, one-shift operation

Item	Year 1	Years 2–10
4/4 blanks:		
Volume (ft²)	806,400	1,612,800
Price/ft²	$1.70	$1.70
Total revenue	$1,370,880	$2,741,760
5/4 blanks:		
Volume (ft²)	276,480	552,960
Price/ft²	$2.12	$2.12
Total revenue	$586,138	$1,172,275

Table 5.—Annual operating expenses, two-shift operation

Item	Year 1	Year 2	Years 3–10
Variable manufacturing costs:			
Lumber			
Red oak 4/4	$ 441,788	$ 883,575	$1,767,150
Red oak 5/4	195,075	390,150	780,300
Supplies	30,000	50,000	100,000
Labor			
First shift	297,000	396,000	396,000
Second shift	0	0	351,000
Utilities	40,000	60,000	100,000
Selling expenses	97,850	195,700	391,400
Fixed costs:			
Management and administrative	130,000	130,000	200,000
Insurance	70,000	70,000	70,000
Maintenance	45,000	55,000	75,000
Total operating expenses	$1,346,713	$2,230,425	$4,230,850

Table 6.—Annual revenues, two-shift operation

Item	Year 1	Year 2	Years 3–10
4/4 blanks:			
Volume (ft²)	806,400	1,612,800	3,225,600
Price/ft²	$1.70	$1.70	$1.70
Total revenue	$1,370,880	$2,741,760	$5,483,520
5/4 blanks:			
Volume (ft²)	276,480	552,960	1,105,920
Price/ft²	$2.12	$2.12	$2.12
Total revenue	$586,138	$1,172,275	$2,344,550

Table 7.—Operating cost summary for producing standard-size blanks for full production at one- and two-shift levels of operation[a]

Item	One-shift costs $	One-shift costs $/ft²	Two-shift costs $	Two-shift costs $/ft²
Variable manufacturing cost (less selling expenses)	1,779,725	0.822	3,494,450	0.807
Fixed manufacturing cost	255,000	.118	345,000	.080
Total operating cost (exclude depreciation on capital investment)	2,034,725	0.940	3,839,450	0.887

[a]Plant product mix—70 percent 4/4 red oak, 30-percent 5/4 red oak.

Table 8.—Total cost for producing standard-size blanks given different percentages of the capital investment depreciated on a straight-line basis over 10 years, in dollars per square foot of output[a]

Item	Capital investment[b] 0% $0	25% $705,403	50% $1,410,805	75% $2,116,208	100% $2,821,610
			One-Shift		
Depreciation	0.0	0.033	0.065	0.098	0.130
Operating cost	.940	.940	.940	.940	.940
Total cost of production	0.940	0.973	1.005	1.038	1.070
			Two-Shift		
Depreciation	0.0	0.016	0.033	0.049	0.065
Operating cost	.887	.887	.887	.887	.887
Total cost of production	0.887	0.903	0.920	0.936	0.952

[a]Plant product mix—70 percent 4/4 red oak, 30 percent 5/4 red oak.
[b]Excludes land and sundry costs totaling $90,000.

Conclusion

The manufacture of standard-size blanks for open-market consumption is a new idea. It seems to have several important advantages that may strengthen its chances for success. First, it uses log-run lumber that contains upwards of 40 percent No. 2 Common—a grade traditionally eschewed by manufacturers of fine hardwood furniture and cabinets. Second, the process we have described is based on existing technologies. Third, because standard-size blanks can be held in inventory, a manufacturer of standard-size blanks would be able to respond in a flexible, timely manner to its own or its customer's demands. These attributes make standard-size blanks an attractive supplemental as well as primary source of solid wood material.

The sale of blanks at the prices and quantities specified will provide acceptable returns for both one-shift and two-shift operations. However, a full two-shift operation enjoys certain economies of scale and promises a substantially better return on investment and lower costs than the one-shift. It is also less susceptible to the adverse consequences of declining revenues or increasing costs. Thus once the operation is established, every attempt should be made to achieve a full two-shift level. For an independent producer of blanks, this will require a considerable marketing effort.

The manufacture of blanks by existing producers of furniture, cabinets, and other wood products seems to be even more promising. Their demand for blanks should be more predictable, as it would be derived from existing markets for the firm's products; production costs are comparable to or lower than present processing costs for dimension; and an external market for blanks might be developed to augment internal demand.

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Appendix

Estimated Building and Equipment Costs

Estimated building and equipment costs for the blanks plant as of October 1980:

1.	Land; 8 acres @ \$10,000 per acre	\$ 80,000
2.	Lumber stacking building (120 × 36 @ \$8 per ft^2)	34,560
3.	Lumber stacker	165,000
4.	Predrier (600 Mbf capacity @ \$0.50 per bd ft capacity)	300,000
5.	Covered storage area (40 × 90 @ \$10 per ft^2)	36,000
6.	Dry kilns (two 90 Mbf capacity @ \$2.25 per bd ft capacity)	405,000
7.	Dry storage area (100 × 122 @ \$14 per ft^2)	170,800
8.	One forklift (22,500-pound diesel)	60,000
9.	Boiler room building (\$14 per ft^2, boiler 250 hp, one 90-ton silo)	250,000
10.	Main building 145 × 145 (pre-engineered superstructure building @ \$14 per ft^2)	294,350
11.	Rough mill system (handling equipment, sorter, etc.) plus scrap handling system	140,000
12.	Two crosscut saws	17,000
13.	Rough planer	50,000
14.	Two edging saws	40,000
15.	Five ripsaws	75,000
16.	Four guide lights	4,000
17.	One salvage chopsaw	2,500
18.	Roll conveyors (\$10 per linear foot per section)	1,000
19.	Two single arbor matching saws	34,000
20.	One 40-section clamp carrier, 8 feet wide, with six 6-inch-wide clamps per section	30,000
21.	One RF gluer	35,000
22.	Abrasive planer (37-inch top and bottom machines)	55,000
23.	Roll conveyors (inventory area)	4,000
24.	Forty factory trucks (\$335 each)	13,400
25.	Double end trimsaw	25,000
26.	Chipping hog	30,000
27.	Dust system	50,000
28.	Bag house	40,000
29.	Compressed air system (screw type 100 hp)	35,000
30.	Electrical installation, complete	125,000
31.	Plumbing installation, complete	50,000
32.	Heating system with humidity control	100,000
33.	Fire protection system	50,000
34.	Office space (4,000 ft^2 @ \$20 per ft^2 for everything except furnishings)	80,000
35.	Office furnishings	20,000
36.	Sundry items (permits, tax, stamps, etc.)	10,000
	Total	\$2,911,610

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Araman, Philip A.; Hansen, Bruce G. **Conventional processing of standard-size edge-glued blanks for furniture and cabinet parts: a feasibility study.** Res. Pap. NE-524. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 11 p.

Each year the manufacturers of furniture and cabinets use over 2 billion board feet of hardwood lumber. As demand intensifies, we will need to utilize more of the abundant lower grade hardwood resource to assure future supplies at reasonable prices. Conventional processing of standard-size hardwood blanks manufactured from log-run red oak lumber, a resource containing over 40-percent low-grade No. 2 Common lumber, has been shown to be technically and economically feasible. Internal rates of return from 26 to 40 percent are possible when blanks are produced for outside sales or replace open-market purchases of dimension. Accounting-based costs of producing 4/4 and 5/4 red oak blanks for internal consumption range from about $0.89 to $1.07 per square foot.

ODC 671, 836.1

Keywords: Hardwood dimension; hardwood lumber, log-run lumber; panels; economic evaluation; internal rates of return

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Department of
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Forest Service

**Northeastern Forest
Experiment Station**

Research
Paper NE-525

1983

System 6

Used to Make Kitchen Cabinet C2F Blanks from Small-Diameter, Low-Grade Red Oak

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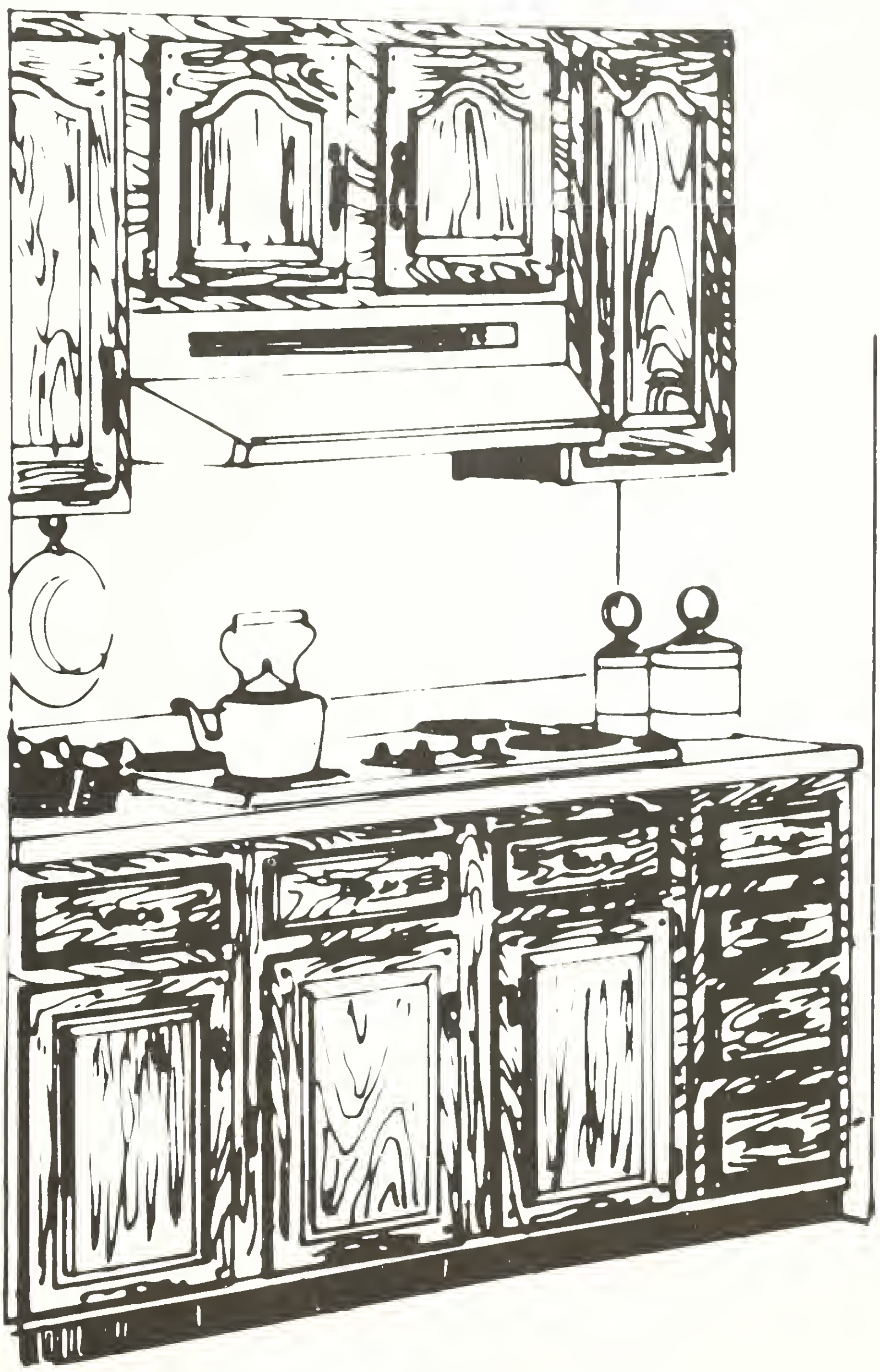

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Abstract

Hardwood dimension manufacturers can make profitable use of plentiful small-diameter, low-grade timber when System 6 technology is used. We describe a System 6 plant designed to make clear-two-face (C2F) blanks for the kitchen cabinet industry. Data for plant operation are taken from a study in which red oak bolts (from a reforestation clearcut) were used to make 33-, 29-, 25-, 21-, and 15-inch-long standard-size blanks. Sem jointing of short pieces was used to increase the quantity of 25-inch blanks. The economics of two options for plant operation is explained.

Computer Disclaimer Statement

Introduction

The hardwood dimension industry makes solid wood parts (cut to rough part sizes, or partly or fully machined) for use in making furniture and kitchen cabinets. The dimension companies usually purchase high-grade hardwood lumber and use regular production techniques to make these parts. However, they could make profitable use of abundant, inexpensive low-grade hardwood timber if they had System 6 plants.

We outline a typical System 6 plant that could be used by a hardwood dimension manufacturer who will make standard-size blanks instead of rough-dimension parts. Data from a study in which red oak bolts were used to satisfy clear-two-face (C2F) blank requirements for a kitchen cabinet company are used to determine plant production. The economics of two profitable methods for operating this plant is given.

System 6 has been explained in a series of research publications. Marketing differences between System 6 and conventional hardwood methods are given by Reynolds and Gatchell (1979). The new technology is explained in a second paper by Reynolds and Gatchell (1982). The process is shown schematically in Figure 1.

Because relatively few C2F blanks shorter than 21 inches were required in the kitchen cabinets made in this study, we included Serpentine end matching (Sem). Sem is a process that joins short pieces to make long pieces (Gatchell et al. 1977). The curved joint has a pleasing appearance when it can be seen, but often it is invisible (Hansen and Gatchell 1978). Although the joint is not as strong as a scarf or finger joint, it is strong enough for furniture and cabinet use (Gatchell and Peters 1981). The joint is made on a tape-controlled router (Coleman 1977).

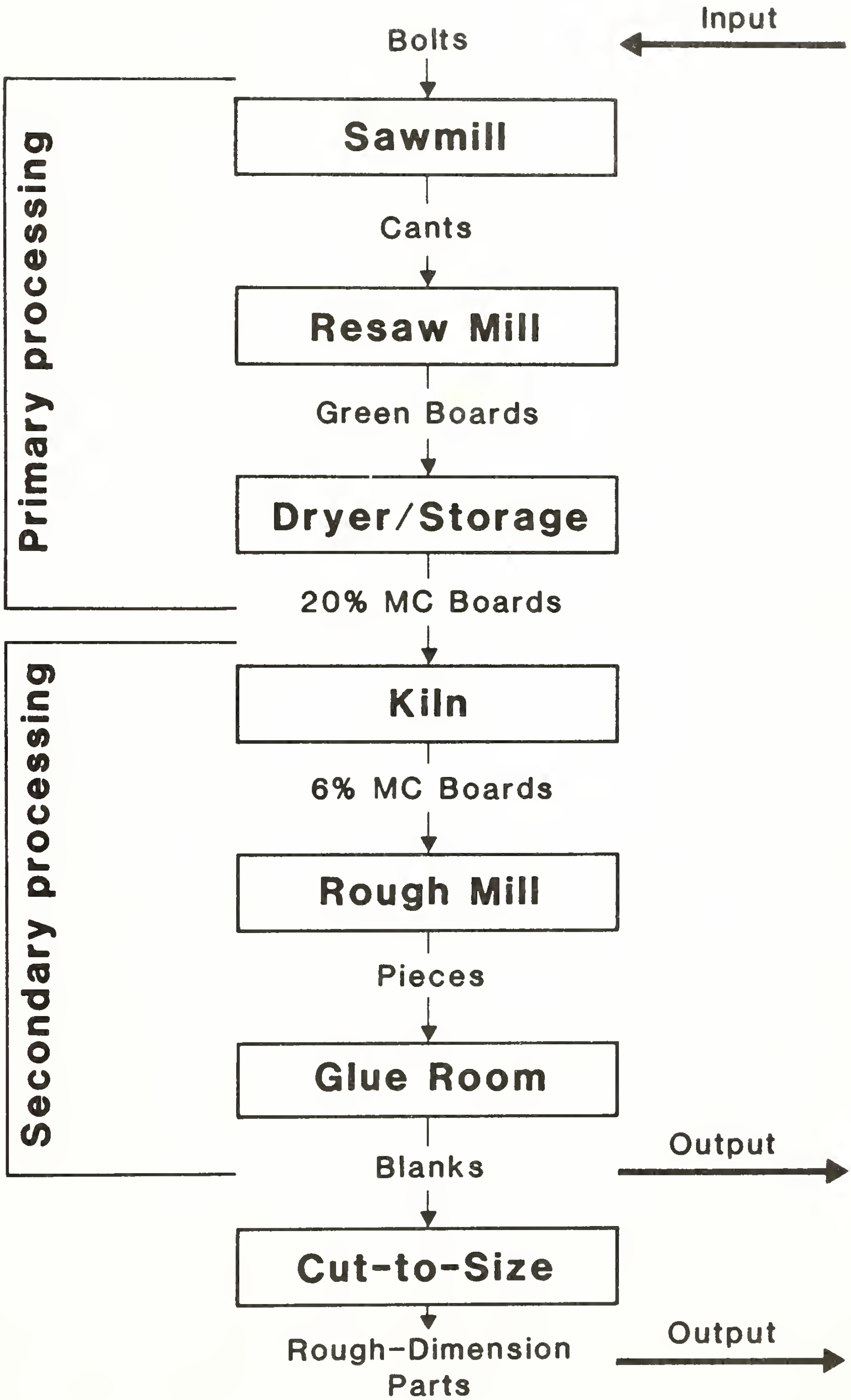

Figure 1.—System 6 process flowchart.

We will discuss five major topics: the System 6 plant, the raw material input—cants, the output product—blanks, manufacturing blanks, and economics. Each of these topics is divided into a general discussion pertinent to all System 6 operations and a specific discussion pertinent to the raw material and methods used to make the required blanks. As compared to a case study, this presentation should give the reader a wider appreciation of System 6.

System 6 Plant

The hardwood dimension manufacturer must have a System 6 plant to convert the small-diameter, low-grade timber to blanks economically. We assume that this will be a new plant in a new location. This assumption exemplifies the "worst case" because conversion of a current operation could use existing land and depreciated buildings, boilers, kilns, and machinery, which would lower costs. So, if a dimension company can make a profit with a new plant, it will profit more when some of the existing equipment and buildings are used.

The System 6 plant uses purchased cants as the raw material input. The primary processing begins at the resaw mill (Fig. 1). Here the cants are resawed to boards. All boards with at least one minimal size clear cutting (1½ by 15 inches) are kept, regardless of wane. Boards are immediately sticker stacked using ½-inch-thick stickers on 2-foot centers. Packages are made 4 feet wide by 3 feet high, each with 400 board feet. Packages are banded by two polypropylene straps to hold the boards and stickers in place during forklift handling. The packages are then transferred to the predrier. After drying to 20 percent moisture content (MC), the board packages are put in storage.

Boards required in the secondary processing end of the plant are transferred in packages to the kilns. After drying to 6 percent MC, the boards enter the rough mill. Here, the boards are made into defect-free pieces of blank lengths. The pieces are laid up into panels and are edge glued to blank widths. Planing the blanks completes the process.

Study Plant

System 6 plants can handle any capacity by adding machinery. A minimum-size plant uses one machine at each key location. Such a System 6 plant is described by Gatchell and Reynolds (1980).

A System 6 plant with one cant gangsaw to make boards from cants, one gang crosscut saw to crosscut boards to pieces, and one gang ripsaw to rip the pieces to specific widths is considered a minimum-size plant. When enough auxiliary equipment is added to keep these key machines running near capacity, the plant can convert 16 Mbf (thousand board feet) of cants to blanks per 8-hour shift. The blank output depends on the quality of blanks being produced.

Our study used a fully equipped 16 Mbf per shift input capacity plant. A 47-man payroll with two supervisors kept the kilns and boiler running 24 hours per day with a single-shift operation making blanks. The plant investment estimates (current of August 1982) are given in Table 1.

Table 1.—System 6 plant investment: 16 Mbf/shift input[a]

Item	Cost	
Machinery:		
Primary processing	$173,000	
Secondary processing	630,000	
Total		$ 803,000
Dryers, kiln, boilers, fuel handling	$637,000	
Buildings	260,000	
Total		$ 897,000
Land and improvements		100,000
Total		$1,800,000

[a] Details on equipment prices are available from the authors.

Raw Material Input

The raw material input for a System 6 plant is two-sided cants. The dimension company usually purchases these cants from hardwood sawmillers. Because System 6 cants are not yet a standard sawmill product, the dimension company will have to deal directly with sawmillers to get the correct cants.

System 6 bolt specifications ıre:

- 8 to 12 inches in diameter, small end inside bark (7.6 inches minimum to 12.5 inches maximum),
- 6 feet long (75 inches actual length),
- Sound quality—rot and dote not permitted, and
- 1½ inches maximum sweep.

The sawmiller saws only two :ants per bolt. The bolt is loaded ɔnto the carriage and is sawed into 3¼- or 4-inch cants (Fig. 2). The ;awmiller should not try to make ɔoards plus cants because it requires too much sawing, and the ıumber of thicker cants is reduced.

Our experience has shown that :he International ¼-inch Rule, withɔut deductions, is a practical scale. Although it underestimates the ɔoard footage sawed from 8- and)-inch-diameter bolts, it will overestimate the board footage sawed 'rom 12-inch bolts. We have found ıo better way to estimate board 'ootage in bolts of the 8- to 12-inchliameter range used to make System 5 cants.

ʀed Oak Cants

We used low-grade red oak :imber obtained from a reforestation :learcut in West Virginia for our ;tudy. A paper company was conıerting a mixed hardwood/softwood ;ite into a softwood pulpwood planation. All good hardwood timber was made to Factory Grade 1 and 2 ;awlogs and to Factory Grade 3 ;awlogs 13 inches and larger. The emaining timber was made to System 6 bolts or to hardwood pulp

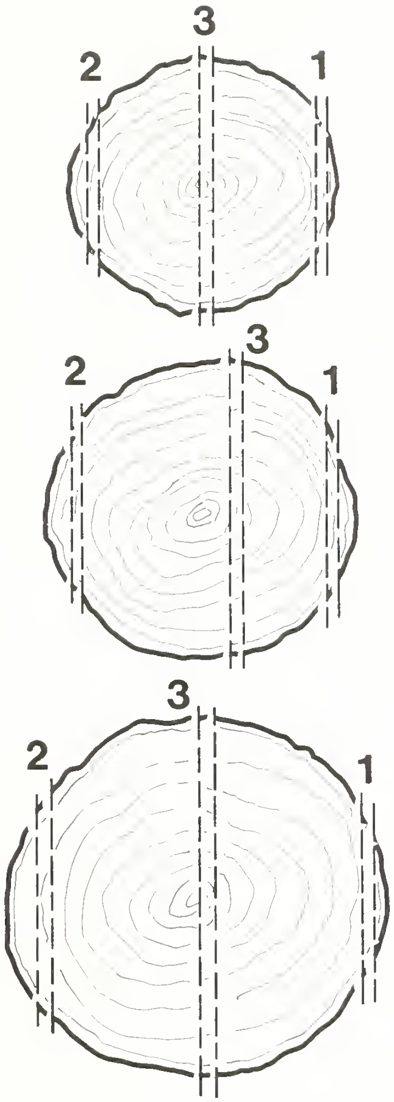

Figure 2.—Bolt sawing patterns.

Small-Diameter Bolts

1. Saw for 3-inch minimum face, turn 180°.
2. Saw to allow for two 3-1/4-inch-thick cants plus kerf.
3. Saw to make two 3-1/4-inch-thick cants.

Medium-Diameter Bolts

1. Saw for 3-inch minimum face, turn 180°.
2. Saw to allow for a 3-1/4-inch and a 4-inch-thick cant plus kerf.
3. Saw to make one 3-1/4-inch and one 4-inch-thick cant.

Large-Diameter Bolts

1. Saw for 3-inch minimum face, turn 180°.
2. Saw to allow for two 4-inch-thick cants plus kerf.
3. Saw to make two 4-inch-thick cants.

bolts. Only the System 6 red oak bolts were used in this study. The bolt-diameter distribution and cant-thickness distribution found in this study (Table 2) are typical of the low-grade, small-diameter hardwood resource required by the sawmiller to meet System 6 bolt and cant specifications.

Cants were valued at $180 per Mbf, free on board the System 6 plant. The rationale for this price is as follows: The sawmiller should pay no more than $100 per Mbf International ¼-inch scale for the System 6 bolts. If he buys by cord measure, this is equivalent to $45 per cord. Our experience with small hardwood sawmillers shows that $50 per Mbf sawing charges will return a profit. System 6 bolt-to-cant sawing is simple and fast. We allow $30 per Mbf to bring the cants from the sawmill to the System 6 plant.

Cant scale versus bolt scale is a difficult choice. We have tried a number of cant scaling techniques and have yet to find one that is accurate and easy to apply. The System 6 cants have only two flat sides and are difficult to measure. We have found that using the bolt footage as the cant footage is possible because only cants are sawed from the bolts (Fig. 2). So, 1,000 feet of bolts become 1,000 feet of cants and no overrun is made in the sawmill.

Table 2.—Bolt and cant distribution by bolt diameter (per 100 bolts)

Bolt diameter		No. of bolts	Bolt[a] scale	No. of cants		
Class	Range (inches)			3¼″ thick	4″ thick	Total
			fbm			
7	6.6- 7.5	2	17	4	0	4
8	7.6- 8.5	2	28	4	0	4
9	8.6- 9.5	14	260	16	12	28
10	9.6-10.5	30	658	18	42	60
11	10.6-11.5	34	908	0	68	68
12	11.6-12.5	12	402	0	24	24
13	12.6-13.5	6	236	0	12	12
Total		100	2,509	42	158	200

[a] International ¼-inch Rule used without deductions.

Table 3.—C2F blank requirements for 10 cabinet sets (all blanks 26 inches wide)

Blank lengths (inches)	No. of blanks	Total blank area	Blank surface area
		Percent	*Square feet*
33	6	9.0	36
29	15	19.8	79
25	29	32.4	131
21	32	30.1	121
15	13	8.7	35
Total	95	100.0	402

Output Product

The output from a System 6 plant always is blanks. Only one thickness and quality of blanks is made during a production run. Blanks can be made in all specific lengths or to a few specific lengths during the production run.

A study by Araman and others (1982) determined cabinet part requirements. These data from 11 major cabinet manufacturers were used to determine the least number of blank lengths that would result in no more than 10 percent end-trim loss when all parts were cut from blanks. For 4/4 thick clear parts, 12 standard blank lengths were determined: 15, 18, 21, 25, 29, 33, 38, 45, 50, 60, 75, and 100 inches long. All clear blanks made are 26 inches wide. Approximately 80 percent of the C2F cabinet parts (by surface area measure) can be made from blanks 33 inches long or less.

C2F Blank Requirements

A major kitchen cabinet manufacturer sent us his cutting bill of parts requirements for eight of his most popular oak cabinets. We translated the C2F parts requirements into C2F blank requirements. The number of blanks to make 10 sets of the eight cabinets is shown in Table 3. None of the C2F parts were longer than 33 inches.

Manufacturing Blanks

Primary Processing

Cants entering the System 6 plant are gang sawed to boards. The spacing between the saw blades determines the board thickness. All boards are sawed to the same thickness. Every board with at least one minimum-size clear cutting (1½ by 15 inches) is sent on to the stacker. After stacking, the packages of boards are brought to the predryer where they are dried to 20 percent MC. This completes the primary part of the System 6 processing.

Each board saved is tallied as a full-width board. Boards made from the rounded side of the cant will have wane on one edge, but they are considered as full width. Thus, each board sawed 4/4 thick, from a 3¼-inch-thick cant 6 feet long, will have 1½-board-foot measure. Each 4/4 board from a 4-inch-thick cant 6 feet long will have 2-board-foot measure.

In our study, all of the red oak cants were 6 feet long, and all were sawed to 4/4 thickness (1.182 inches actual). The usual System 6 practice is to use all boards, and grading is not done. However, in this C2F blank study, we wanted to test the feasibility of grading the boards into two groups: those boards grading No. 3A Common and Better and those not meeting the No. 3A Common grade.

After drying, the boards were graded by National Hardwood Lumber Association (NHLA) rules dropping the minimum lumber length and width requirements. Every board, regardless of wane, sawed from a 3¼-inch-thick cant and saved was tallied as a 3-inch board. For grading purposes, each of these boards must have at least one 3- by 24-inch clear cutting on the grade (poorer) face to qualify as No. 3A Common. Every board, regardless of wane, sawed from a 4-inch-thick cant and saved was tallied as a 4-inch board. For grading purposes, each of these boards must have at least one 3½- by 32-inch cutting or two 3- by 24-inch cuttings on the grade face to qualify as No. 3A Common. Obviously, most boards from the outside of the cant would not qualify as No. 3A Common or Better no matter how good they were because waney edges would make them too narrow.

The board distribution by grading was 39 percent of the board footage at No. 3A Common and Better and 61 percent below No. 3A Common (below grade).

We then compared total board output to cant input. For every 1 Mbf of cants (input) we had a total of 960 board feet of kiln-dried boards (output). This is a 4-percent underrun of boards from cants.

Secondary Processing

Packages of boards, at 20 percent MC, are transferred to the dry kilns for drying to 6 percent MC. The seven-step rough-mill process to make the defect-free pieces in the lengths required and to edge glue the pieces to blanks is:

1—Rough planing
2—Gang crosscutting to selected lengths
3—Gang ripping of pieces to specified widths
4—Defecting by crosscutting to blank lengths
5—Salvage ripsawing to specified widths when edge defects still remain
6—Edge gluing
7—Surfacing

In the 16-Mbf System 6 plant, we added a Sem option at step 4. Any piece entering step 4 that cannot have defects removed by being trimmed to a selected blank length is sent to the Sem room without being trimmed. These pieces have Sem joints made so the defects are removed. The Sem joints are then glued together and the piece is trimmed to a specified blank length and returned to the rough mill at step 5, where it is given a glue-joint edge on both sides.

System 6 rough-mill operation is simple. In general, follow the same sequence regardless of what blanks you are making. Two qualifications to this statement are: first, gang crosscutting lengths are selected depending on the blank lengths to be produced; and second, the pieces are made to the blank quality specifications. In this work, each piece was made to C2F quality standards as defined by Araman and others (1982).

In System 6 rough-mill operation, the rough-mill operators are permitted to work freely without interruption and to make as many blanks as possible in each length. A production control feature, unique to System 6 and discussed later, permits the rough-mill foreman to know in advance how many packages of kiln-dried boards must be used to produce the blanks needed.

In our study, we selected two gang crosscut saw spacings—gang crosscut lengths one and two (GCL-1 and GCL-2). In GCL-1, three saws are set up with 36 inches between saws 1 and 2 and 36 inches between saws 2 and 3. In GCL-2, four saws are set up with 29 inches between saws 1 and 2, 21 inches between saws 2 and 3, and 25 inches between saws 3 and 4. We anticipated that the 29-inch cuttings, because they are cut first, would help satisfy both the 29- and 25-inch requirements.

The seven-step rough-mill instructions that we followed are shown in Table 4. In GCL-1, any piece entering step 4 that could not be made into a 21-inch C2F piece was made into a 15-inch piece and Sem was not used. In GCL-2, any piece entering step 4 that could not be made into a C2F 21-inch piece was sent to the Sem room without being trimmed.

In the Sem room, scrap pieces were matched by width, grain (edge or flat), and color (light or dark). Each two matching piece set was then machined in the Sem router, the pieces were end-glued, and were then cut to a 25-inch length. The Sem machining and cutting to length were done so that the resulting 25-inch piece was of C2F quality. The Sem-joined 25-inch pieces were brought back to the rough mill at step 5 (Table 4) where they were ripped (glue joint edges) to the four allowable widths.

We ran half of the boards that did not meet No. 3A Common grade (below grade) using GCL-1. The C2F pieces were sorted by length, and the surface area of pieces per length was tallied. Then we ran half of the boards that met or exceeded No. 3A Common grade (No. 3A Common and Better) using GCL-1. Again, we sorted the C2F pieces by length and tallied the surface area per length.

The results are shown in Table 5. First, we combined the below grade and No. 3A Common and Better yields together to get the yield when all boards were used and presented the results in output per 1 Mbf of boards input. We also show the yields when 1 Mbf of the No. 3A Common and Better boards are used. Because the pieces are edge-glued to blank widths without loss of surface area, the piece surface area and the blank surface area are the same.

We ran the second half of the below-grade boards using GCL-2. We sorted by length and totaled the piece surface area. However, in the 25-inch piece lengths, we made two area measurements: those pieces with and without Sem joints. We then ran the second half of the No. 3A Common and Better boards using GCL-2. Again, we sorted by length and totaled the piece surface areas keeping the 25-inch with and without Sem pieces separated.

The GCL-2 yields based on output per 1 Mbf of boards input are shown in Table 5. We combined the yields from below-grade boards and No. 3A Common and Better boards when the 25-inch Sem-joint pieces were added to the 25-inch pieces without Sem. We used the yields from the No. 3A Common and Better boards when all the 25-inch pieces, with and without Sem, were added. We then computed these two totals without the 25-inch Sem-joint pieces, which enabled us to detect the effect of Sem on blank yield.

Production Control

In the System 6 plant, the input cants are made to System 6 boards and the boards are dried. The plant operators need a way to determine, in advance, the minimum board footage that must be rough milled using each GCL to obtain the required blanks.

System 6 secondary processing is designed to run without interruption until all the boards to be cut by the given GCL have been used. Then, the next GCL is set up and all the boards to be used are processed without stopping. The operators are not concerned with the quantities of blanks needed per length. When all the GCL's have been used and all the boards have been cut, all of the blanks needed will have been made. But not all blanks made will be the correct length. There will always be too many blanks in the longer lengths. It is a function of the production control technique to provide instructions on trimming the excess longer blanks to the required shorter blanks.

Table 4.—Rough-mill instructions

Step	GCL-1	GCL-2
1. Rough planing	Plane first side at 1.050″; second side at 1.000″	
2. Gang crosscut	36 and 36	29, 21, 25 (as remainder)
3. Gang ripsaw	1½, 2, 2½, 3, 3½	1½, 2, 2½, 3, 3½
4. Remove defect and trim to length	33, 29, 25, 21, 15	29, 25, 21, scrap to Sem
5. Salvage rip (if required) Sem jointing	1½, 2, 2½, 3 Not used	1½, 2, 2½, 3 25″ pieces only
6. Edge gluing	33 × 26, 29 × 26, 25 × 26, 21 × 26, 15 × 26	29 × 26, 25 × 26, 21 × 26, with 25″ Sem-joined and full-length pieces alternated
7. Surfacing	Abrasive plane both sides to 0.875″ (7/8) thickness	

Table 5.—Blank outputs per board quality input and by GCL (values in square feet of blanks surface area output per 1,000 board feet of boards input)

Board quality	Blank length					Total blank output
	33	29	25	21	15	
	Inches					
	GCL-1					
All boards	120	36	56	65	67	344
No. 3A Common and Better only	247	49	75	48	43	462
	GCL-2 (includes 25″ Sem pieces)					
All boards		84	92	204		380
No. 3A Common and Better only		168	89	284		541
	GCL-2 (without Sem)					
All boards		84	37	204		325
No. 3A Common and Better only		168	34	284		486

Table 6.—Minimum System 6 board footage input for GCL-1 and 2 to obtain the required blanks by board quality GCL and Sem use

ption	Board quality	Sem use	System 6 board input			Blank output	Yield
			GCL-1	GCL-2	Total		
				fbm		*Square feet*	*Percent*
1	All	Yes	528	620	1,148	402	35.0
2	All	No	1,276	126	1,403	402	28.7
3	No. 3A Common and Better	Yes	816	133	949	402	42.4
4	No. 3A Common and Better	No	818	145	963	402	41.7

We have two techniques to ptimize the production of blanks.)ne makes use of linear programing LP) in the computer program S60PT, nd the other is a manual technique. Both are available from the authors. he manual technique is time consuming but not difficult. The LP nodel runs very rapidly and requires hat the computer be capable of ising a 15 by 50 matrix. The soluions in this paper were determined ising the manual technique, but the P model will give the same results.

We tested four combinations we call them options) of GCL's and em to determine how many System boards must be used to make the lank requirements shown in Table 3. The yield data per GCL are taken from Table 5. The four options are:

1. Use all boards with GCL-1 and GCL-2 using Sem.
2. Use all boards with GCL-1 and GCL-2 without Sem.
3. Use No. 3A Common and Better boards only with GCL-1 and GCL-2 using Sem.
4. Use No. 3A Common and Better boards only with GCL-1 and GCL-2 without Sem.

The results of the production optimization are shown in Table 6.

Options 3 and 4 use only the No. 3A Common and Better boards to make the required C2F blanks. The low-grade red oak cants used in our study had approximately 40 percent of all board footage in this grade classification. We consider that the 60 percent below No. 3A Common grade boards will be made into lower quality blanks. A discussion of this dual quality production of blanks is given in the economics section.

In the first option, roughly half of the System 6 boards were cut up using each GCL (46 percent GCL-1; 54 percent GCL-2). Almost all of the blanks were used without trimming (92 percent). The remaining blank requirements were made by trimming long blanks to shorter blanks. An 11-percent trim loss occurred but this was not serious as only a few blanks had to be trimmed. There was also 1 square foot of 21-inch blank surface area remaining.

When Sem was not used (the second option), the yield changed drastically. It was best to run almost all the boards using GCL-1 (91 percent). Only 59 percent of the blanks were used without trimming and those trimmed had an 18-percent waste. In addition, there were 50 square feet of 15-inch blanks remaining.

When only the No. 3A Common and Better boards were used, the use of Sem did not increase the yield much. In both options 3 and 4, most of the board footage (85 percent) was cut using GCL-1. However, only half (56 percent) was used without trimming, and the other half of the blank requirements was trimmed from longer blanks with a 24-percent trim loss. However, no extra blanks were made.

Options 1 and 2 apply when only C2F blanks are made because all boards will be used. Option 1 is superior to option 2 because of a higher yield and because so little blank trimming must be done. But, if only the better boards are used to make C2F blanks, option 4 is better than option 3 because Sem is not required. The economic viability of options 1 and 4 follows.

Economics

Will a new System 6 plant be profitable making the required C2F blanks using either options 1 or 4? We will make an economic analysis to determine the effects of cant input costs, manufacturing costs, C2F blank price, and working capital as compared to the plant investment. We use a cash flow analysis (CFA) program originally written by Harpole (1978) and adapted by Hansen for System 6 use.

To use the CFA program, the costs to produce blanks must be divided into fixed and variable costs. The revenues from the sales of blanks must also be calculated. The capital investment is divided into working capital, land, machinery, and buildings. The internal rate of return (IRR) is then determined.

Option 1

We analyzed option 1, which uses all the boards, GCL-1 and GCL-2, and Sem. The yield of required blanks was 35.0 percent of the System 6 board-footage input (Table 6). The System 6 plant has a 16.0 Mbf per shift input capacity. The blank output will be 5,600 square feet of blanks per shift.

We will set the C2F blank selling price at $1.95 per square foot, based on industry values in August 1982. If the System 6 plant runs a single shift of 240 days per year, the annual blank production will be 1,344,000 square feet worth $2,620,000.

We found that 1 Mbf of cants produced 960 board feet of System 6 boards, a 4-percent underrun. Therefore, the dimension company will have to purchase 16.6 Mbf of cants to produce 16.0 Mbf of boards per shift. The primary processing mill has the ability to handle this additional 4-percent cant footage.

The additional variable and fixed costs are shown in Table 7. The primary processing end of the plant has a 10-man, 1-foreman crew. Secondary processing has a foreman and 16 men plus 2 men for Sem, 5 men for full-time kiln operation, and 9 men for making the C2F pieces to planed blanks. Five men are required for full-time boiler and wood-fuel operation. The supplies, utilities, and so on are estimated using other CFA's for reference.

Working capital was estimated from cant costs (30-work-day supply)

Table 7.—Annual operating costs and revenues: C2F blanks from all boards (option 1)

Item	Year 1[a]	Year 2–10
Costs: Variable		
Cants $180/Mbf × 16.6 Mbf/shift × 240 shifts/year	$ 358,500	$ 717,000
Labor 47 men @ $6/hour plus 2 men @ $10/hour	453,000	604,000
Supplies	23,000	39,000
Utilities	31,000	52,000
Selling expenses	65,500	131,000
Costs: Fixed		
Management and administrative	70,000	70,000
Insurance	45,000	45,000
Maintenance	48,000	80,000
Costs: Total	$1,094,000	$1,738,000 (66% of sales)
Revenues: C2F blanks 1,344,000 ft^2 × $1.95/$ft^2$	$1,310,000	$2,620,000

[a] During the first year, only half the annual production will be made.

Capital investment:		
	Land	$ 100,000
	Working capital	298,000
	Machinery and buildings	1,700,000
	Total	$2,098,000

ınd from the 30-day waiting period)etween the time the blanks were ;hipped until payment was received.)epreciation was based upon the ıew Accelerated Cost Recovery System. Accordingly, machinery was depreciated over 5 years and buildngs over 15 years. Land was not depreciated. The undepreciated value of the assets and working capital was added to the after-tax cash flow in year 10. A tax rate of 46 percent was used in all analyses.

The CFA for this System 6 plant naking C2F blanks using all the)oards cut up by GCL-1 and GCL-2 with Sem shows a 21.3-percent rate of return (after taxes). The total nvestment was $2.098 million.

Option 4

The second choice that we analyzed was option 4, which makes C2F blanks using GCL-1 and GCL-2 without Sem from only the No. 3A Common and Better boards. In option 4, the boards are separated as they are fed into the rough planer —step 1 in the rough mill. The No. 3A Common and Better boards (40 percent of all boards) are put through the planer, and the remainder (60 percent) set aside for later use. It requires only 96 shifts per year to make the C2F blanks, and 144 shifts per year to cut up the below grade boards.

In option 4, Sem is not used, so capital investment is reduced by $100,000 and two men are taken from the System 6 payroll. The total investment is $2.0 million. We divided the capital investment and annual operating costs into a per-shift basis. Costs and investment for making the C2F blanks are 96/240 (40 percent) of the annual totals. We made 640,000 square feet of C2F blanks (per year) at $1.95 per square foot. This revenue compared to the partial costs and investment has a 34.8-percent rate of return. We used the same CFA as that in option 1.

If we make frame blanks from the below-grade boards on the other 144 shifts per year, we will expect a lower rate of return. A 56.0 percent yield of frame blanks from white oak below-grade boards was found in a previous study (Reynolds and Araman 1983), and we can expect the same from the red oak below-grade boards used in this research. We could make 1,290,000 square feet of frame blanks per year at $1 per square foot. This revenue compared to the partial costs and investment had a 10.2-percent rate of return.

The CFA of the total $2.0 million investment and the total operating costs for a full 240 shift per year to produce 640,000 square feet of C2F blanks and 1,290,000 square feet of frame blanks showed a 20.9-percent rate of return.

Internal Use of Blanks

The dimension company may decide not to sell C2F blanks at $1.95 per square foot but instead use the blanks to make the kitchen cabinet parts themselves. Given the likelihood of this eventuality, we have prepared an accounting-based cost summary so that existing accounting cost information can be used to further evaluate the blanks opportunity. In keeping with convention, the accounting cost summaries do not include any allowance for the cost of land, selling expenses, or working capital. As a result, operating costs in Table 7 would be reduced to $1,607,000 annually. Dividing this cost by the 1,344,000 square feet results in a cost per square foot of $1.20. Building and equipment costs are expressed through 10-year, straight-line depreciation allowances amounting to $0.13 per square foot. Combining the operating and depreciation costs results in a total cost per square foot of blank of $1.33 (option 1).

In deriving the cost per square foot of making C2F blanks via the fourth option, we used the costs and investment charges associated with that 40 percent of production—96 shifts—yielding C2F blanks. The annual operating costs less selling expenses came to $0.99 per square foot. Depreciation allowances for building and equipment came to $0.10 per square foot for a total cost of $1.09 per square foot of C2F blanks.

Increased Rate of Return

We stated that a dimension manufacturer presently making parts may wish to use existing equipment, buildings, and so on to make the System 6 plant, and the CFA's that we used indicate the effects of such a practice. When all boards are used to make C2F blanks as described in option 1 and the capital investment is reduced by 20 percent, the rate of return will increase from 21.3 to 25.5 percent. If only the No. 3A Common and Better boards are used as described in option 4, reducing investment by 20 percent will increase the rate of return from 34.8 to 41.0 percent.

Recommendations

Small-diameter, low-grade hardwood utilization to make C2F quality blanks using System 6 can be profitable. For an initial $2 million investment in a completely new System 6 plant, the owners can expect at least a 21.3-percent return on their investment. If C2F and other quality blanks are made, the return on investment will be better. If a company presently making rough-dimension parts from lumber converts to System 6 and low-grade hardwoods, much of the present equipment and buildings can be used, thereby reducing capital investment and bringing the rates of return well into the range of 30 percent.

Before making C2F blanks for sale or for internal use:

- Determine the C2F standard blank requirements.
- Determine if other blanks will be required, and if so, what requirements per blank quality will be met.
- Determine the quality of the input cants by sampling possible material sources.
- Decide if the two GCL's and options 1 and 4 used in this study are adequate or if others should be devised and tested.
- Determine the size of the blank market and design the System 6 plant accordingly.
- Run CFA programs to test the economic feasibility of proposed operations before the System 6 plant is built.

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Reynolds, Hugh W.; Araman, Philip A.; Gatchell, Charles J.; Hansen, Bruce G. **System 6 used to make kitchen cabinet C2F blanks from small-diameter, low-grade red oak.** Res. Pap. NE-525. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 11 p.

Hardwood dimension manufacturers can make profitable use of plentiful small-diameter, low-grade timber when System 6 technology is used. We describe a System 6 plant designed to make clear-two-face (C2F) blanks for the kitchen cabinet industry. Data for plant operation are taken from a study in which red oak bolts (from a reforestation clearcut) were used to make 33-, 29-, 25-, 21-, and 15-inch-long standard-size blanks. Sem jointing of short pieces was used to increase the quantity of 25-inch blanks. The economics of two options for plant operation is explained.

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Keywords: Furniture manufacturing; lumber drying; hardwood dimension

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Sticky-Board Trap for Measuring Dispersal of Spruce Budworm Larvae

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Abstract

Describes a new sticky-board trap for measuring early-larval dispersal of the spruce budworm, *Choristoneura fumiferana* (Clem.), and evaluates trap-board color and screened versus unscreened traps. Dispersing spruce budworm larvae showed no preference for trap color; fewer nontarget arthropods were caught on dark-colored than on light-colored traps. Screened traps caught significantly more spruce budworm larvae than unscreened traps, and they were easier to examine.

·oduction

Small larvae of the spruce bud-·m, *Choristoneura fumiferana* ·m.), are susceptible to dispersal ·nediately after eclosion when 1st ·ars are searching for overwinter-· sites, and the following spring ·n 2nd instars are seeking feed-· sites. Spring emergence and ·ersal can be predicted accurately ·alculating degree-day accumula-·s above a threshold temperature ·an 1961; Cameron et al. 1968; ·er et al. 1971). Mortality generally ·igh during both dispersal periods ·ler 1958; Morris and Mott 1963; ·t 1963), and dispersal is affected ·umerous factors including ·st-stand density and species ·position (Morris and Mott 1963), ·-crown closure (Kemp and Sim-·s 1979), and air turbulence ·llington and Henson 1947; Henson ·).

Traditionally, investigators have ·sured early-larval dispersal ·*rectly*. Population counts are ·le of: 1) new egg masses laid on ·t-tree needles, 2) overwintering L_2 ·ae in hibernacula, and 3) feeding ·nd L_4 larvae in buds and shoots ·following spring. After accounting ·gg and overwintering mortalities, ·erences in these population ·sities are attributed largely to ·ersal losses or wastage (Miller ·3; Greenbank 1963; Kemp and ·mons 1979). However, to better ·erstand the intrinsic nature of ·ersal and to account for such ·es, more *direct* methods are ·ded for measuring early-larval ·ersal of the spruce budworm.

This paper describes a new ·ky-board trap for capturing dis-·ing spruce budworm larvae, and ·uates trap-board color and ·ened versus unscreened traps.

Materials and Methods

Trap Design

A flat board trap, the Maine Trap, was constructed by fastening a 30- by 30- by 0.6-cm piece of tempered hardboard to a 5- by 5- by 80-cm presharpened stake with a hanger bolt assembly (Fig. 1). To facilitate mounting the board to the stake, a 4.8-mm hole was drilled in the center of the board. The hanger bolt assembly has both machine and wood threads. Two 0.6-cm nuts (1.3 cm in diameter) were locked together about 2 cm below the bolt top to support a protective screen for screened traps.

The protective screen was fashioned from a 46- by 46-cm piece of galvanized hardware cloth (1.3-cm mesh). The screen was cut with metal-cutting snips and folded into an "open-sided box" about 30.5 by 30.5 by 7.6 cm. Needle-nose pliers were used for handling screen corners and hooking loose wire ends. Two 0.8-cm washers (1.9 cm in diameter) and a third 0.6-cm nut were used to support and fasten the protective screen above the sticky board.

Figure 1.—Sticky-board trap for measuring early-larval dispersal of spruce budworm.

Trap Color

Because some insects are attracted to a specific color, e.g., aphids to yellow (Roach and Agee 1972), thrips to white (Lewis 1959), bark beetles to red (Entwistle 1963), colored sticky-board traps may attract large numbers of "nontarget" insects, making examination for spruce budworm larvae difficult and time consuming. We designed an experiment to determine whether a particular color was least attractive to nontarget insects, and whether spruce budworm larvae were attracted to a specific color.

We tested white, black, orange, red, yellow, green, blue, brown, and brown (unpainted). We used Deshler®[1] interior/exterior glossy enamel paints. Trap boards were first sealed with a wax-base floor sealer and then spray painted with three coats for uniform coverage. Three coats were necessary because we used untempered hardboard for this experiment. One board was left unpainted to give nine treatments.

Each treatment was completely randomized within a randomized block design; blocks were replicated 5 times. Within each block, traps were spaced 2 m apart; blocks were 4 m on each side. Individual blocks were spaced 10 to 20 m apart in a dense spruce-fir forest infested with spruce budworm. Three blocks were in a line; two blocks were in an offset line.

Traps were deployed on the Penobscot Experimental Forest, Penobscot County, Maine, on May 13, 1977, and retrieved on June 3, 1977. Some larval dispersal had already taken place by the earlier date; a few balsam fir shoots were found with webbing and established larvae on May 14 and 15.

After retrieval from the forest, trap boards were examined in the laboratory and counts made of arthropod groups: Diptera, Coleoptera, Hymenoptera, Homoptera, Collembola, Araneae, Thysanura, Lepidoptera (adults), and spruce budworm larvae. Analysis of variance and Duncan's Multiple Range Test were used to determine significant differences among treatments and replications.

Screened vs. Unscreened Traps

During spring dispersal of L_2 larvae, three pairs of sticky-board traps were deployed on April 25, 1978, in each of five widely separated plots on the Penobscot Experimental Forest. All test plots had overstory spruce-fir infested with spruce budworm. One trap of each pair was chosen at random and screened (Fig. 1); the other was left unscreened (Fig. 2). Pairs were spaced 3 m apart with individual pair members 1 m apart.

After larval dispersal ceased, traps were retrieved on May 22, 1978, and transported to the laboratory for examination and counting of spruce budworm larvae.

Figure 2.—Unscreened sticky-board trap.

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture, the Forest Service, or the University of Maine, of any product or service to the exclusion of others that may be suitable.

ɪsults and Discussion

p Design

Specifications of the new trap ign are shown in Figure 3. Pro- ures for cutting and bending the tective screen are shown in ɹre 4.

For installing the traps, we first ɪe the presharpened stake about ːm into the ground with a ham- or mallet. Premarking the ɪes to driving depth helped main- uniform trapping height above ınd. A wrench was used to screw ınt the hardboard to the stake by ıns of the hanger bolt assembly . 3). Once in place, sticky erial (Tack Trap®) was applied ıe hardboard with a spreader.[2]

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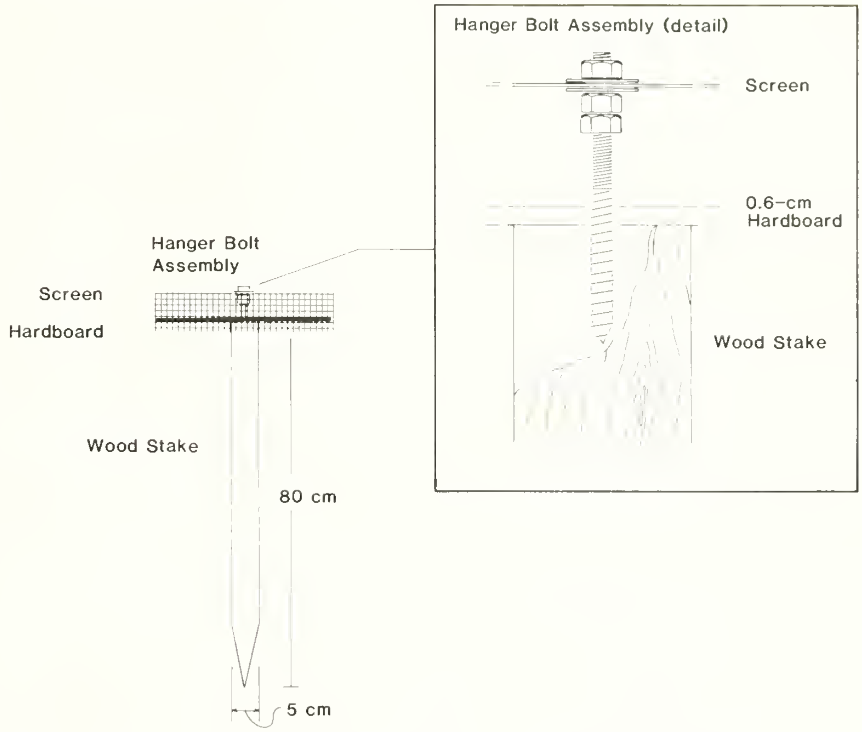
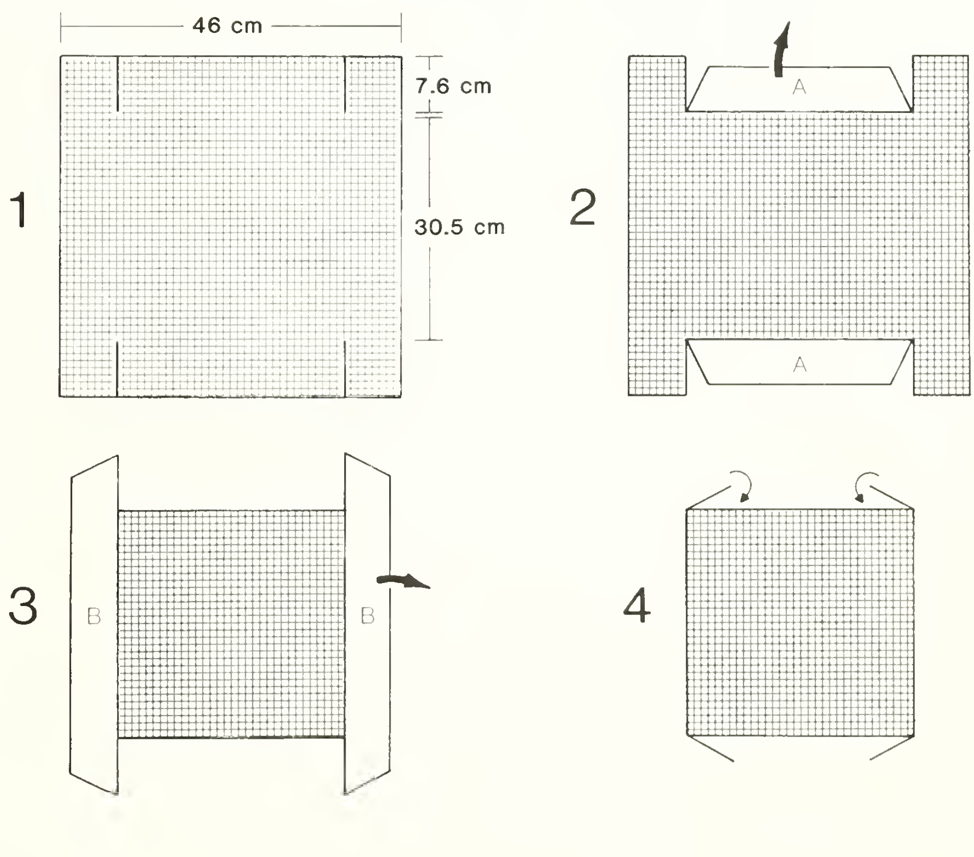
Figure 3.—Specifications of the Maine Trap.





re 4.—Procedure for cutting and ng protective screening, ıe Trap.

Trap Color

Analysis of variance indicated highly significant differences due to treatment (color), arthropod group, and interaction of treatment x arthropod group (Table 1). There was no significant difference between replications, indicating uniformity between replications.

Significantly more Diptera were caught on the trap boards than any other arthropod group (Table 2). Mean numbers of Hymenoptera trapped differed significantly from all other groups except Coleoptera. Catches of remaining arthropod groups were about the same and were not significantly different over all replications and treatments.

In general, more insects and spiders were caught on light-colored than on dark-colored traps (Table 3); however, not all mean catches were mutually exclusive. Yellow and green traps caught the most arthropods, but mean specimens per trap did not differ significantly from those on white or blue traps. The fewest number of arthropods was caught on black traps; however, mean specimens per trap did not differ significantly from those on the other dark-colored traps (brown unpainted, red, and brown).

Table 1.—ANOVA statistics for sticky-board color experiment, Penobscot Experimental Forest, Maine

Source	Sum of squares	df	F value
Total	1303.4×10^4	404	
Replications	1.3×10^4	4	1.11
Treatment (color)	10.9×10^4	8	4.72**
Arthropod group	1132.9×10^4	8	488.34**
Treatment x group	65.4×10^4	64	3.52**
Error	92.8×10^4	320	

**$P \le 0.01$

Table 2.—Total and mean numbers of insects and spiders caught on sticky-board traps by arthropod group, all colors and replications, Penobscot Experimental Forest, Maine

Arthropod group	Total caught	Mean per trap[a]	SD
Diptera	24366	541.47a	193.23
Hymenoptera	1939	43.09b	34.73
Coleoptera	1188	26.40b	11.36
Collembola	221	4.91c	5.77
Spruce budworm larvae	148	3.29c	3.03
Lepidoptera (adults)	138	3.07c	2.50
Araneae	129	2.87c	1.88
Thysanura	101	2.24c	2.50
Homoptera	100	2.22c	1.77

[a]Means followed by the same letter are not significantly different at $P \le 0.05$ (Duncan's Multiple Range Test).

Table 3.—Total and mean numbers of insects and spiders caught on sticky-board traps by color, all arthropod groups and all replications, Penobscot Experimental Forest, Maine

Treatment color	Total caught	Mean per trap[a]	SD
Yellow	4294	858.80a	172.80
Green	4222	844.40ab	238.80
White	3506	701.20abc	213.74
Blue	3238	647.60abc	193.48
Orange	3120	624.00bc	128.37
Brown (unpainted)	2852	570.40cd	159.84
Red	2774	554.80cd	96.37
Brown	2435	487.00cd	79.09
Black	1889	377.80d	102.84

[a]Means followed by the same letter are not significantly different at $P \le 0.05$ (Duncan's Multiple Range Test).

Only Diptera, Hymenoptera, and Coleoptera showed significant differences among trap-board colors. Most Diptera were caught on light-colored traps (green, yellow, and white), but mean catches per trap were not significantly different from those on blue and brown (unpainted) traps. Significantly more Hymenoptera were caught on yellow traps than on any other trap. Color preferences for Coleoptera, in descending order of mean catches per trap, were: blue, orange, red, brown, green, white, and yellow. Significantly fewer Coleoptera were caught on brown (unpainted) and black traps than on other traps.

As expected, spruce budworm larvae demonstrated no particular preference for trap-board color (Table 4); mean numbers of larvae per trap were not significantly different ($P \leq 0.05$) among treatment colors. This lack of color preference is not surprising because L_1 and L_2 budworm larvae have little control over pattern of dispersal. Directional movement is predominantly downward except when larvae are displaced laterally or upward by air currents. Perception of substrate color followed by a behavioral "choice" is unlikely for these early-stage larvae. Our data indicate that dispersing spruce budworm larvae were not differentially attracted to and caught on traps of different colors.

Table 4.—Total and mean numbers of spruce budworm larvae caught on sticky-board traps by color, Penobscot Experimental Forest, Maine

Treatment color	Total larvae caught	Mean[a] larvae per trap[b]	SD	Coefficient of variation
				Percent
Orange	23	4.60	2.51	55
White	23	4.60	2.19	48
Green	22	4.40	3.78	86
Blue	16	3.20	4.55	142
Brown (unpainted)	16	3.20	3.35	105
Red	15	3.00	3.39	113
Yellow	12	2.40	3.78	158
Black	11	2.20	1.92	87
Brown	10	2.00	1.87	94
Total	148	3.29	3.03	92

[a]Means are not significantly different at $P \leq 0.05$ (ANOVA and Duncan's Multiple Range Test).

[b]900 cm^2

Screened vs. Unscreened Traps

Considering all plots, paired t-tests indicated more larvae were caught on screened ($\bar{X}$ = 9.07) than on unscreened traps ($\bar{X}$ = 6.40) (Table 5), but only one plot showed significantly higher mean numbers of larvae on screened than on unscreened traps. Moreover, screened traps generally had fewer nontarget insects and less debris, making them easier to examine. Mean examination time per board did not differ significantly ($\bar{X}$ = 48.6 minutes for screened boards and $\bar{X}$ = 52.9 minutes for unscreened boards), but examination time was shorter for screened boards.

Table 5.—Paired t-tests for mean differences in catches of L_2 spruce budworm larvae, screened and unscreened Maine Traps, Penobscot Experimental Forest, Maine

Plot no.	Screened		Unscreened		*t*
	$\bar{X}$	SD	$\bar{X}$	SD	
8	5.00	2.00	1.00	1.00	2.62
22	18.67	5.51	12.33	1.53	1.61
4	7.33	5.03	7.33	4.51	0.00
12	8.33	2.31	5.00	2.00	5.00*
9	6.00	2.00	6.33	3.51	0.18
All tests	9.07	5.99	6.40	4.48	2.33*

*$t \leq 0.05$.

Conclusions

On the basis of these results, we recommend that sticky-board traps for measuring early-larval dispersal of spruce budworm be painted red and have a protective screen. Although fewer insects and spiders were caught on brown and black boards than on red boards (Table 3), spruce budworm larvae are difficult to distinguish against dark colors. And, unpainted (brown) boards tend to absorb sticky materials, leaving splotches of relatively dry, untacky surfaces. Red is the next best color because it provides good contrast for examining budworm larvae.

We found no evidence that screening interferes with trapping efficiency. Although dispersing larvae landing on the trap's screen or on the hanger bolt conceivably could escape via the screen, the screened traps usually caught more larvae than unscreened traps. The data also indicate a tendency for screened traps to catch more larvae than unscreened traps as the dispersing larval population increases.

Unscreened traps have the distinct disadvantage of capturing birds and small mammals. Three unscreened boards showed signs of bird activity (i.e., bird feathers stuck on the trap board), and one bird was caught. Apparently, birds are attracted to insects caught on the sticky-board traps.

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Jennings, Daniel T.; Houseweart, Mark W. **Sticky-board trap for measuring dispersal of spruce budworm larvae.** Res. Pap. NE-526. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 7 p.

Describes a new sticky-board trap for measuring early-larval dispersal of the spruce budworm, *Choristoneura fumiferana* (Clem.), and evaluates trap-board color and screened versus unscreened traps. Dispersing spruce budworm larvae showed no preference for trap color; fewer nontarget arthropods were caught on dark-colored than on light-colored traps. Screened traps caught significantly more spruce budworm larvae than unscreened traps and they were easier to examine.

ODC 450

Keywords: *Choristoneura fumiferana*; larval dispersal; trap color; trap design; sampling methods.

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The Personal-Use Firewood Program on Three National Forests: a Cost Analysis

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Abstract

The national forests provide a substantial volume of firewood for America's households. The 17 national forest districts studied spent over $148,000 to provide over 25,000 personal-use firewood permits during the calendar year 1981; 86 percent of the permits were for freewood mostly in the form of dead or down wood. The remaining 14 percent were for greenwood sold either to households in the form of pickup load sales or through the sale of personal-size boundaries of marked timber. It cost the 17 districts almost $6.00 per permit to provide this service. The cost per permit varied by the district issuing the permit and by the system used to provide the wood. The cost by district ranged from less than $0.50 to $32.00 per permit; by system the cost ranged from approximately $2.80 for a dead or down permit to over $56.00 a permit to prepare a personal-size sale.

Introduction

The public forests of the United States, particularly the national forests, are becoming an important source of personal-use firewood. Until 1973, only residents within or near a national forest boundary could obtain a permit to cut firewood on the forests for their own use. However, in 1971 only a small percentage of even the rural population used firewood and of those residents eligible, only a few were requesting permits; for example, the Monongahela National Forest issued less than 300 permits that year.

In 1972, the first energy crisis occurred. The demand for wood increased, and wood started to regain its place as an important alternative home fuel. From July 1972 to June 1973, 64,000 free-use permits were issued by the USDA Forest Service nationwide. This increase in requests for wood was followed by the USDA announcement in late fall of 1973 that even more people would be allowed to cut national forest firewood for their own use.[1] In 1977, as the oil problems continued and a very cold winter caused heating costs to soar, all rules for issuing wood permits in all eastern national forests were further liberalized.[2] Today, all who wish to cut wood for their personal use may apply for a permit for Forest Service firewood.

In 1981, when this study was initiated, the national forest firewood program was being operated under Interim Directive No. 60, Forest Service Manual 2460, that instructed all Forest Service officers to make personal-use firewood available to all potential users so long as other resource values were protected and consistent with manpower and budget constraints. The permits issued to cut personal-use firewood were to be free, but under situations demanding increased use of manpower or resources, fees could be charged. In February 1981, the interim directive was replaced by Amendment 124, Forest Service Manual 2460.

"Freewood" is still the norm; however, the selling of wood ("feewood") has been increasing in some forests. This increase in feewood has been due in part to demand that has depleted the accessible firewood in many areas and increased the cost of preparing additional firewood areas and protecting the other resources.

Each district decided how to make wood available to potential users. Although a major portion of the wood leaving the forest is still given to the user, it is not a cost-free activity for the Forest Service. The cost of making firewood available to the public accrues to the Forest Service except in a few situations where it would cost more to dispose of residue and other normally unwanted wood than to make it available for firewood.

My study was undertaken to determine what it costs a national forest district to provide firewood for personal use. I considered the relative merits of the numerous systems used to provide firewood, which is that wood from a national forest for one's own energy use and not to be resold, traded, or otherwise transferred.

Procedure

Cost data pertaining to firewood were collected for 12 months from January 1 through December 31, 1981. The data were gathered from a total of 17 districts of the George Washington, Jefferson, and Monongahela National Forests. The study area was in the central Appalachians and covered a variety of demand situations from those of rural-scattered to urban-compact populations, resulting in a large range in the number of permits issued by the ranger districts.

The information collected from each of the 17 ranger districts included a description of each system used to transfer wood to individuals and the number of permits issued under each system. A permit is an authorization issued by the forest district at the request of or purchased by an individual that allows the removal of a given volume of wood or the designated wood from a given area within each system. The following cost-related items were recorded:

Labor (for each employee who did work within the personal-use firewood program)

- Job classification, grade, and pay rate
- Pay differential—if any: overtime, night, Sunday
- Number of hours or portion thereof worked

Vehicle (mileage charges)

- Class or type
- Miles driven

Other

- Office supplies, including mailing costs
- Field supplies

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[1] U.S. Department of Agriculture, Forest Service. USDA to let public cut free firewood to ease energy situation. In the Forest Service Firewood Program (by Susan Johnson, Policy Analysis), Appendix Ia, News, USDA 3558, 1973. 2 p.

[2] U.S. Department of Agriculture, Forest Service. Forest Service expands free firewood policy. In the Forest Service Firewood Program (by Susan Johnson, Policy Analysis), Appendix Ib, News, USDA 321, 1977. 1 p.

- Monthly vehicle charges
- Contractual costs
- Forest Service equipment charged by the operating hour

Labor and vehicle use also were recorded as administrative (e.g., permit writing, inspection, law enforcement) or nonadministrative (tree marking, road work).

For any activity conducted primarily for the production of firewood, all times and expenses were entered on the study data sheets. However, if firewood was a byproduct of some activity, only those additional times and expenses incurred in making the firewood available to the public were recorded.

Labor costs were computed by multiplying the times worked by the appropriate pay classification scale and then by pay differential, if any. The vehicle costs were computed by multiplying the miles driven by the vehicle class rates for the appropriate region. We used pay scales and vehicle rates in force for the month that work or travel was accomplished and for districts in which the employee or vehicle was assigned.

Permits Issued and Systems of Transfer

In the study area, individuals can obtain wood by one or more of six systems, or a variation thereof. These systems vary among forests and among districts within a forest. These systems listed in descending order by number of districts using the system are:

- 1—Free dead or down wood (usually for up to 5 cords or equivalent Ccf's [one Ccf = 100 ft^3] per permit)
- 2—Small sale units (greenwood, usually marked, within a defined boundary)
- 3—Pickup load sales (usually cut your own)
- 4—Small free units (greenwood, usually marked, within a defined boundary—marked units usually less than 1 acre)
- 5—Free greenwood (individually marked trees within a district)
- 6—Areas set aside for or sold to groups (e.g., a senior citizens cutting area)

In the study area for the 12-month period ending December 31, 1981, over 25.000 firewood permits were issued. The breakdown of permits issued for forests A, B, and C was 54, 34, and 12 percent, respectively (Table 1). One basic reason why forest C issued relatively fewer permits than forest A or B is differences in forest setting. Some of the districts in A and B are very similar to districts in C. But, in general, forest C differs in a number of respects from A or B as follows:

- Low population density
- No population center within easy driving range
- Accessible privately owned wood

Permits issued within a given system for the whole study area ranged from 89 for System 5 to over 20,000 for System 1. System 1 or some variation thereof was the only system used by all 17 districts. The dead or down permit accounted for 82 percent of all permits issued in the study area (Table 1). Only three districts issued less than 69 percent of their total permits as dead or down; in five districts it was the only system used. The remaining five systems all involved mostly greenwood (live standing trees).

Table 1.—Permits issued by system and forest, in percent

Permit Systems	Forest A N = 13,583	Forest B N = 8,682	Forest C N = 3,067	Total N = 25,332
1. Dead or down	81(57–100)[a]	91(69–100)	62(17–98)	82(17–100)
2. Small sale unit	2(0–6)	2(0–22)	3(0–7)	2(0–22)
3. Pickup load sales	17(0–43)	7(0–21)	—	12(0–43)
4. Small free unit	—	—	32(0–81)	4(0–81)
5. Free greenwood	—	—	3(0–24)	<0.5(0–24)

[a]Numbers in parentheses are the ranges, in percent, among the districts.

The most common greenwood y em, System 2, involves the sell- n of marked trees within small c ndaries ranging up to 10 acres. o ever, the unit is usually a small r containing 3 to 5 cords. Units n offered to the public as follows: y id, where the buyer sets the r e; by lottery, where the seller e the price; or on a first-come, r -served basis, where the seller e the price. However, where e and exceeds supply, the last e nod has caused problems and s complaints. Although nearly n half of the districts use System accounts for only about 2 per- e of the total permits issued, but i gaining popularity among the i icts.

System 3 (truckload sales) has e used or tried by nearly 30 e ent of the districts. Under this y em, areas with marked trees, t ds which are to be clearcut, and o etimes areas of logging residue r set aside and the wood is sold y e truckload. Recipients cut and a their wood and pay a set fee for e oad. System 3 accounted for 12 e ent of the total permits issued. r ne district, 43 percent of the e nits were for truckload wood.

In System 3, the number of e nits does not equal the number f cipients because each truckload o nsidered a permit and a recipi- n nay purchase more than one a for his own use.

Of the three remaining systems, n System 4 is relatively impor- a System 4—small free units of a ed firewood—is carried on by w districts and accounts for 4 e ent of total permits issued in e study area. However, for the r t in which the two districts are c ed, almost one-third of the e nits were issued under this y em. The units usually are about n half of an acre and contain 3 or n cords of firewood. The mate- a o be cut is marked, the unit o daries marked, and the units u bered. They are then assigned n first-come, first-served basis.

One of the two districts offering free firewood in this form of small units of timber has plans to sell these units in the future.

System 5 and 6 account for 3 percent of the total funds expended for the firewood program and less than 0.5 percent of the permits issued. System 5 is free greenwood from specifically marked trees scattered throughout a district. Permits are issued under this system by only two districts. Most of the other districts provide greenwood in this form but allow it to be cut under a standard or modified dead or down permit.

System 6, active on only 1 of the 17 districts at this time, provides personal-use firewood to groups. In this system, areas are set aside and then given or sold to a designated group (e.g., a senior citizen area or an area acquired by a co-op for use by their own members). Four units were made available under this system; however, the number of persons cutting from these areas is unknown, so this system was not included in Table 1.

Cost and Analysis

The three categories of expenditures for this study broke down as follows: transportation, and other costs accounted for 20 percent of the firewood program expenditures; the remaining 80 percent was for labor. By district within the study, the labor costs ranged from 69 to 100 percent (Table 2).

The 17 districts spent over $148,000 to operate the personal-use firewood program during calendar year 1981. The average cost was just over $8,700 per district. The range of expenditures per district was from less than $300 to over $25,000 (Table 2).

It cost an average of $5.85 (Table 3) to provide a permit for firewood by one of the six basic systems. The respective costs for forests A, B, and C were $4.32, $7.58, and $7.69 (Table 4). The forest with the lowest cost issued the most permits, 53 percent of the total for the study area during 1981.

At the district level, the overall cost per permit ranged from less than $0.50 to over $32.00. Both the

Table 2.—Breakdown of cost by expense category and forest, in percent

Expense category	Forest A $58,647 (4.8–40.1)[a]	Forest B $65,839 (0.4–38.0)	Forest C $23,583 (9.2–42.8)	Total $148,070
Labor	78(69–90)	78(71–100)	90(75–96)	80
Vehicle use	6(2–14)	13(0–21)	6(4–13)	9
Office supplies	2(0–3)	1(0–8)	2(0–6)	1
Field supplies	6(0–13)	1(0–4)	2(0–8)	4
Other	8(0–16)	7(0–12)	—	6

[a]Numbers in parentheses are the ranges, in percent, of districts' share of forest cost.

Table 3.—Cost analysis for the study area (Permits issued = 25,329)

Item	Nonadministrative				Administrative		
Hours worked (number)							
Forest Service funds	6,901				6,835		
NonForest Service funds	1,683				1,522		
Wages paid (dollars)							
Forest Service funds		54,444				53,062	
NonForest Service funds		5,640				5,169	
Vehicle operation							
Mileage (miles)	27,119				23,590		
Cost (dollars)		6,337				4,366	
Other (dollars)							
Field supplies		5,148					
Vehicle rent (FOR)		1,250				1,088	
Contractual services		1,660					
Forest Service equipment operation		7,722					
Nonfield supplies						2,164	
Total (dollars)		82,201				65,850	
All costs (dollars)				148,051			
Cost per permit (dollars)			3.25				2.60
Total cost per permit (dollars)				5.85			

Table 4.—Cost per permit by forest and district, in dollars

National forest	District 1	2	3	4	5	6	Average
			ALL SYSTEMS				
A	4.82	4.80	3.66	4.48	2.79	5.26	4.32
B	.33	4.97	32.61	6.35	3.92	6.34	7.58
C	4.69	8.34	14.64	6.46	3.77	—	7.69
						Area Average	5.85
			DEAD OR DOWN (SYSTEM 1)				
A	3.24	2.14	2.33	1.35	2.79	0.81	2.16
B	.33	4.81	11.32	6.34	1.46	2.62	3.95
C	3.56	1.76	1.09	1.70	1.67	—	2.20
						Area Average	2.81
			SMALL SALE UNITS (SYSTEM 2)				
A	21.32	58.22	29.99	([a])	([a])	236.50	49.84
B	([a])	198.07	66.07	([a])	([a])	([a])	68.17
C	53.55	134.28	([a])	([a])	37.46	—	42.73
						Area Average	56.82
			PICKUP LOAD SALES (SYSTEM 3)				
A	40.11	8.13	([a])	7.45	([a])	([a])	7.99
B	([a])	([a])	37.03	([a])	([a])	20.72	21.35
C	([a])	([a])	([a])	([a])	([a])	—	([a])
						Area Average	10.93
			SMALL FREE UNITS (SYSTEM 4)				
A	([a])	([a])	([a])	([a])	([a])	([a])	([a])
B	([a])	([a])	([a])	([a])	([a])	([a])	([a])
C	([a])	9.61	21.71	([a])	([a])	—	15.11
						Area Average	15.40

([a]) District did not use this system.

lowest and highest permit costs were for two districts on the same forest (Table 4). The low-cost district (under $0.50 per permit) had a fairly active firewood program in the years before this study. But because of problems and costs associated with the free firewood program, they moved toward selling to firewood entrepreneurs. They now operate a very modified firewood program issuing down-only permits and provide no other service.

The high-cost district ($32.00 per permit) views the firewood program as an integral part of its overall district program. They have tried various systems to provide firewood, and they maintain a very active program. With the approach of last year's firewood season, this district had to build access roads to firewood areas. The road building was one factor in their high-cost permits.

The above district is typical. In fact, its costs may be very typical of a district's firewood program for any given year. The firewood program is a relatively new program for the Forest Service and as such, new problems arise. Demand for wood continues to increase and accessible wood is depleted, so new areas need to be opened, and new ways of providing wood are tried. Solutions to the problems result in cost fluctuations. This has occurred already in some districts; it will occur in others.

The cost of providing a firewood permit is related to the system used. Among the six systems, the average cost per permit ranged from $2.81 for the dead or down system to over $56.00 to prepare a small sale unit (Table 4). Within this range it cost $10.93 to provide a pickup load and $15.40 to provide greenwood from a given free cutting unit. One district expended $19.76 to provide firewood through marked scattered firewood trees. Within each system, the cost per permit fluctuated among the districts (e.g., dead or down permit ranged from $0.33 to $11.32).

A leading cause of cost variation is the philosophy of the ranger and those assigned to the firewood program on a given district. The control of the firewood program since its inception has been left very much to the district. Therefore, the portion of a district's resources that is assigned to the firewood program lies with the ranger and his staff. How they view the program has a definite influence on the assigned resources and the system(s) used in carrying out the Forest Service firewood program.

One district may elect to issue down-only permits and to provide no other service. On another district, in addition to issuing a permit for dead as well as down wood, the district may provide one or more of the following services: maps depicting possible firewood locations, personal aid in locating wood, dead trees designated by some form of marking, and temporary roads constructed into areas containing a concentration of dead and/or down timber.

General economic conditions also are causing increased program costs. Commercial timber sales are down and as a result, less logging residue is available for firewood. Consequently, other sources of firewood must be found, made accessible, and prepared for the public. Because some of these added costs in 1 year benefit the program for 2 or more years, the cost fluctuates from year to year and district to district.

Another reason for cost differences is the size of the program in relation to other service programs. The firewood program is relatively small compared to other district operations. So, even small changes in input cost factors are somewhat magnified and influence the permit cost accordingly.

Special-program personnel (Young Adult Conservation Corps [YACC], Older Americans) in the firewood program are another viable cost factor. These employees work on Forest Service projects but are paid from appropriations of another agency. Pay rates are lower than those for other Forest Service employees. In the study area firewood program, special-program personnel account for 19 percent of the hours worked but only 9 percent of the labor costs (Table 3). Replacing special-program personnel with Forest Service personnel and maintaining the firewood program at or near its present level would cost 2 to 2-1/2 times that of the special-program personnel. Under present policies, this cost would have to be absorbed by the affected districts.

Volume

Volume was not considered in this study because of the difficulty in determining actual volume removed. The volume usually allowed under the dead or down permit or the free permit area is 5 cords or equivalent in Ccf's. Some people probably took the allowable volume. But forest personnel estimate that the majority removed somewhat less than the allowable amount. One ranger estimated that only 2 cords per permit were removed. In addition, substantial volumes of marked firewood are not tallied. Some districts only estimate the volume of designated firewood, others tally only that wood in the sawtimber or pulpwood-size category.

Monetary Returns of the Program

Monetary return does not directly aid the district or forest because monies received go to the General Treasury. Therefore, the cost to the district remains the same regardless of any income from a firewood activity. Income to the General Treasury from the feewood system offsets general appropriations to the Forest Service.

Districts that offered some form of feewood were asked to compile an account of the monies received from the sale of personal-use firewood during the study period. The computation was complicated because the study period covered parts of 2 fiscal years. Further, there is no firewood functionary account and incoming monies were recorded under other accounts. However, most districts provided a fairly accurate estimate of monetary return.

Two districts returned a profit of over $54.00 per sale for the small-sale-unit permits. When all costs of all permits for these districts were accounted for, one district realized a profit of $0.35 per permit; income for the other district served to reduce the average cost per permit from $4.82 to $0.51. Other districts using the feewood systems were able to reduce overall per-permit expenses by up to 60 percent (Table 5).

Table 5.—Actual district cost and effective general revenue per permit for selected districts selling firewood, in dollars

Districts	District cost			Effective general revenue		
	All permits	Small cutting units only	Small cutting units and pickup loads	All permits	Small cutting units only	Small cutting units and pickup loads
A1	4.82	21.32	24.82	− 0.51	+ 54.63	+37.90
A2	4.66	58.22	49.42	− 2.29	([a])	+ .19
A3	3.66	29.99	([b])	+ .35	+ 54.71	([b])
A6	5.26	236.50	([b])	− 2.44	−129.00	([b])
B3	32.61	66.07	60.95	−19.39	([a])	−30.06
B6	6.34	([c])	20.72	− 5.31	([c])	−15.71
C5	3.77	37.46	([b])	− 1.48	+ 1.57	([b])

[a]Revenue from sale of small cutting units and pickup loads not reported separately.
[b]Pickup system (3) not used.
[c]Small cutting unit sales system (2) not used.

Conclusion

- In terms of growth and service to the public, the firewood program is a success. Increased demand has forced many districts to open up additional accessible firewood sources.

- It now costs an average of almost $6.00 to issue a permit for firewood, and this cost will likely increase. In calendar year 1981, some districts spent $200.00 or more to provide wood to one permittee.

- Although some general revenue is derived from the program, the districts must bear the full cost of the operations.

- The program has grown and should be considered a functional program that merits specific budget accounts (at least in areas of high demand).

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The national forests' personal-use firewood program was studied to determine operating costs. Seventeen national forest districts studied expended over $148,000 to provide over 25,000 personal-use firewood permits during the calendar year 1981; 86 percent of the permits were for freewood, mostly dead or down wood. The remaining 14 percent was for greenwood sold to households in the form of pickup load sales or personal-size boundaries of marked timber.

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Research
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Growth of Appalachian Hardwoods Kept Free to Grow from 2 to 12 Years after Clearcutting

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The Author

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Abstract

Free-to-grow sapling-size, yellow-poplars of seedling origin outgrew similar black cherry and red oak in both dbh and total height (especially on good sites). Yellow-poplar consistently grew faster in dbh throughout the study, particularly on the better oak sites. Black cherry had an edge over yellow-poplar in total height during the early years of the study, but yellow-poplar began to outgrow black cherry about 5 and 10 years after clearcutting on the good and fair sites, respectively. Sugar maple did not respond to the annual release treatment. With the annual release techniques used in this study, free-to-grow yellow-poplar grew faster than black cherry in height and dbh, with red oak a distant third during the first 10 to 12 years after clearcutting; however, red oak is more competitive with these intolerants on fairer sites.

Introduction

Silviculturists interested in growing high-quality hardwoods want to increase the number of better quality crop trees in the upper crown canopy. There are at least three approaches to keeping quality trees in the upper crown canopy of young even-aged stands:

1. Thin precommercial stands lightly and often, beginning as soon as the crown closes.
2. Thin precommercial stands once, perhaps 10 to 15 years before the first planned commercial thinning.
3. Do not thin young stands until the first commercial thinning.

The research reported in this paper used option 1, thin lightly and often, to maintain trees in a free-to-grow crown class position where the crowns receive light from all sides. Previous information on growth response of Appalachian hardwoods by crown class positions has been reported by Trimble (1968; 1969; 1975). That information was primarily for commercial-size, second-growth hardwoods. The purpose of this study was to determine the early sapling growth response of young trees maintained in a free-to-grow crown class position.

Study Area and Methods

The study was done on the Fernow Experimental Forest near Parsons, West Virginia. This area has approximately 130 to 145 frost-free days and an average of about 60 inches of precipitation annually. Two study areas were used, one with a northern red oak site index of 75 and the other with a site index of 62. Soils on the better site were DeKalb silt loam, derived largely from sandstone with possibly some limestone influence from adjacent areas. The "fair" site soils were Calvin silt loam derived from acid shale sandstone. Both loams ranged from 2 to 4 feet deep.

Both study areas were clearcut: all trees 1.0 inches dbh and larger were cut. Two years after clear-cutting, stems of four species were selected and released annually thereafter to keep them free to grow. Light reached all sides of the tree crown, although the actual crown class of the study trees in the stand was mainly codominant throughout the study. Annual release was discontinued 12 years after clearcutting on the good site and 11 years after clearcutting on the fair site.

Initially red oak, *Quercus rubra* L.; yellow-poplar, *Liriodendron tulipifera* L.; and black cherry, *Prunus serotina*, Ehrh.; stems of seedling-origin were selected on each site, while sugar maple, *Acer saccharum* Marsh. trees were studied on the good site only. Fifteen study trees of each species were selected and released on each site. Individual study trees were a minimum of 25 feet apart. Annual measurements of total height, length of clear bole, and when possible, dbh at 4.5 feet above the ground were recorded for each individual tree.

Results

Survival

Good site. After 12 years, 14 of the yellow-poplar saplings and all 15 black cherry saplings were living. Seven of 15 red oak saplings were living, as were six of the selected sugar maple study trees.

Fair site. Eleven years after clearcutting, all annually released yellow-poplar trees and 14 of 15 black cherry and red oak trees were alive.

Dbh response

Good site. As indicated in Table 1, the earliest dbh measurements were recorded at the 5-year measurement period when the trees were more than 4.5 feet tall. Among the four measured study species on this site, yellow-poplar consistently had the largest dbh and the fastest dbh growth during the study period. Yellow-poplar averaged 3.0 inches in dbh 12 years after clearcutting while black cherry, red oak, and sugar maple averaged 1.9, 1.1, and 0.2 inches dbh, respectively (Table 1). Most of the living sugar maple study trees were not tall enough to have a dbh measurement. The annual dbh growth during the 12th growing season was 0.54 inch for yellow-poplar, 0.24 for black cherry, and 0.08 for red oak (Fig. 1).

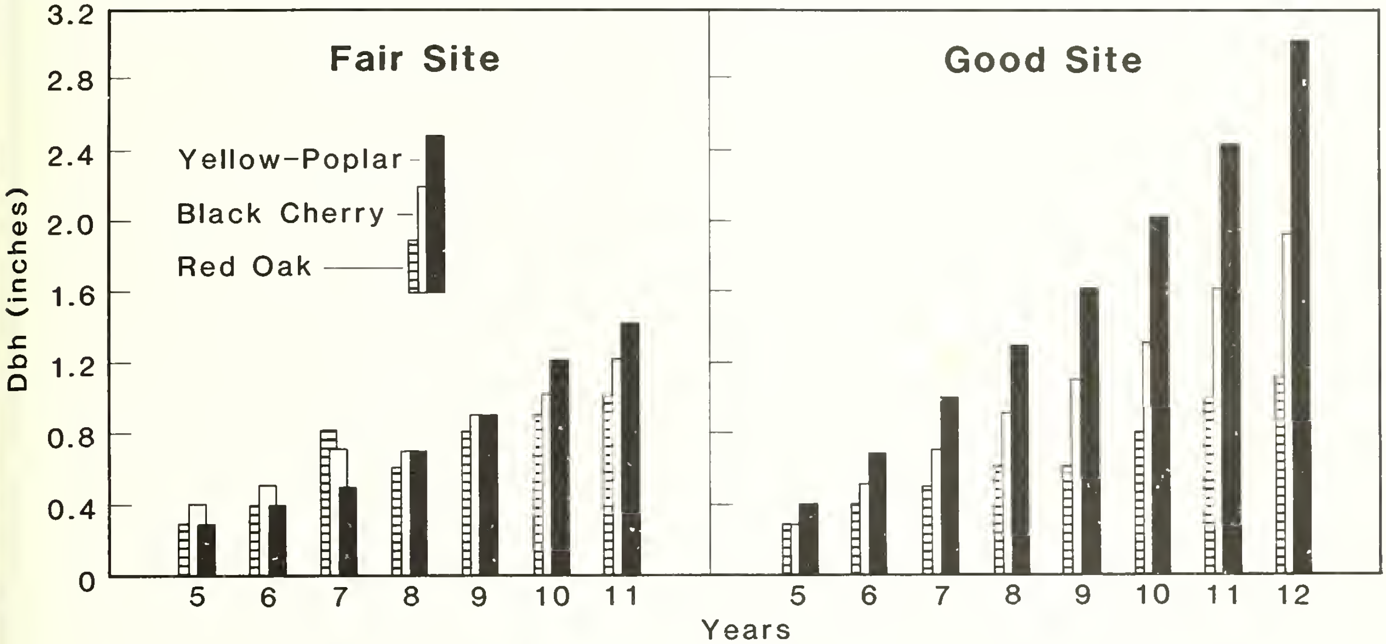
Fair site. Though annually released yellow-poplar maintained a higher dbh growth than the other species, the average difference in dbh among the three species after 11 years was much closer on the fair than the good sites—yellow-poplar 1.4 inches, black cherry 1.2, and red oak 1.0 inches dbh (Table 1). The annual dbh growth for the 11th growing season was about 0.20 inch for both the yellow-poplar and black cherry. Red oak averaged 0.1 inch in annual diameter growth.

During the early years after clearcutting, black cherry was the largest of the three species (in dbh), but during the 9th year, yellow-poplar surpassed the cherry in dbh, and remained larger throughout the rest of the study period (Table 1).

Table 1.—Average annual dbh, total heights, and clear bole lengths for hardwood species released annually to a free-to-grow crown class position on two oak sites

Years since clearcutting	Good site (SI 75)				Fair site (SI 62)		
	Yellow-poplar	Black cherry	Red oak	Sugar maple	Yellow-poplar	Black cherry	Red oak
	Dbh (inches)						
5	0.4	0.3	0.3	—	0.3	0.4	0.3
6	0.7	0.5	0.4	—	0.4	0.5	0.4
7	1.0	0.7	0.5	—	0.5	0.7	0.8
8	1.3	0.9	0.6	0.1	0.7	0.7	0.6
9	1.6	1.1	0.6	0.2	0.9	0.9	0.8
10	2.0	1.3	0.8	0.2	1.2	1.0	0.9
11	2.4	1.6	1.0	0.2	1.4	1.2	1.0
12	3.0	1.9	1.1	0.2			
	Total Height (feet)						
2	1.5	1.8	1.3	0.8	1.2	3.0	1.6
3	3.1	3.8	2.3	1.4	2.4	4.3	2.8
4	4.9	5.6	3.6	2.3	3.4	5.3	3.6
5	6.4	6.8	4.8	2.6	5.1	6.6	5.1
6	9.1	8.8	6.6	3.4	5.9	8.2	6.8
7	11.6	11.1	8.2	3.7	7.1	10.0	7.8
8	14.7	13.6	9.5	4.4	8.8	11.4	9.3
9	17.4	15.3	10.4	4.9	11.5	12.9	10.8
10	21.4	17.7	12.1	5.3	13.7	14.6	12.2
11	23.7	19.8	14.0	5.7	16.5	15.4	13.7
12	28.4	21.5	15.6	5.8			
	Length of Clear Bole (feet)						
5	3.2	2.7	2.3	1.1	2.3	2.6	2.4
6	3.9	4.1	3.0	1.5	3.3	3.4	3.2
7	4.6	4.5	3.6	1.6	3.2	3.8	3.4
8	6.2	6.0	5.3	1.6	4.0	4.4	3.8
9	7.3	6.7	5.4	1.9	4.1	5.3	4.9
10	8.3	8.1	6.2	2.1	5.2	6.1	5.9
11	9.9	8.0	5.4	1.8	5.7	6.6	6.2
12	9.8	8.2	5.5	2.0			

Figure 1.—Periodic dbh response of free-to-grow yellow-poplar, black cherry, and red oak stems on two oak sites.

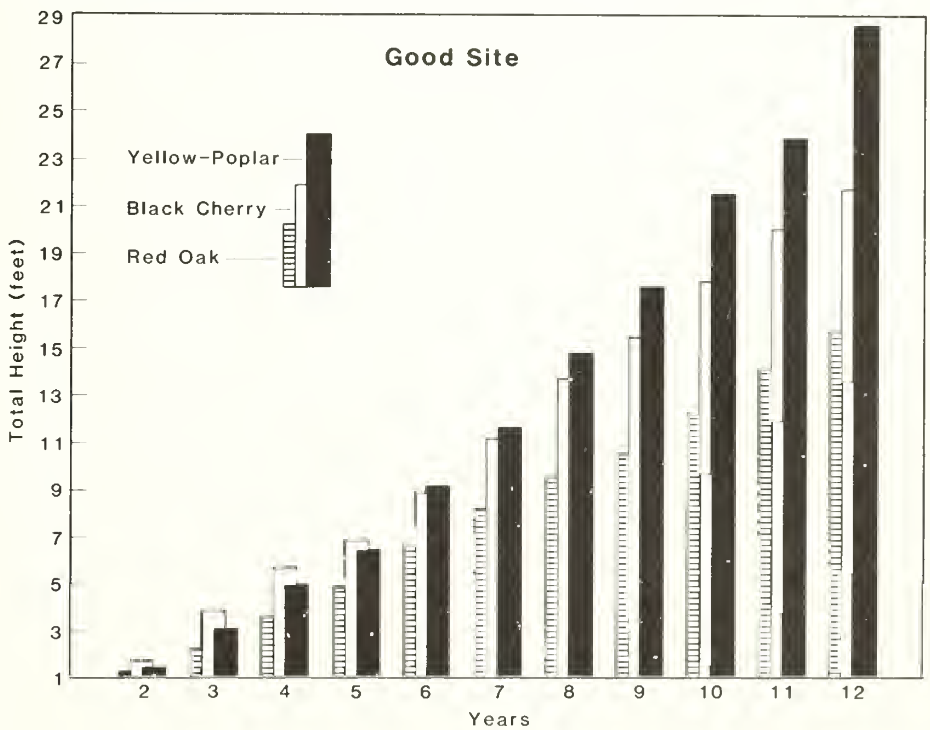


Total Height

Good site. Yellow-poplar was also the tallest of the four study species, averaging 28.4 feet 12 years after clearcutting, when black cherry averaged about 21.5 feet, red oak 15.5 feet, and sugar maple about 6.0 feet (Table 1). The annual height growth at the 12th year after clear-cutting averaged about 4.7 feet for yellow-poplar, 1.7 feet for black cherry, and 1.5 feet for red oak (Table 1). Annual height growth for maple saplings was less than 0.5 feet. This was attributed to seedling mortality and shoot dieback (Fig. 2).

Fair site. As on the good site, yellow-poplar saplings were taller than the black cherry and red oak 11 years after clearcutting—averaging 16.5 feet compared to 15.4 feet for black cherry and 13.7 feet for red oak (Table 1). Annual height growth for yellow-poplar was 2.8 feet for the 11th growing season. This was about 0.5 feet more than similar growth on the good site. Growth for the 11th

Figure 2.—Periodic total height response of free-to-grow yellow-poplar, black cherry, and red oak stems on a site with oak site index 75.



year after clearcutting was 1.5 feet for red oak while black cherry averaged 0.8 feet. Also, during this 11th year, the yellow-poplar passed the black cherry in average total height on this site (Fig. 3).

On the good site, the average initial heights of the black cherry, yellow-poplar, and red oak seedlings differed by only 0.5 foot (1.5, 1.8, and 1.3, respectively). On the fair site, the difference in average height between species was 1.8 feet, with yellow-poplar having an average initial height of 1.2, red oak 1.6, and black cherry 3.0 feet.

Clear Bole Length

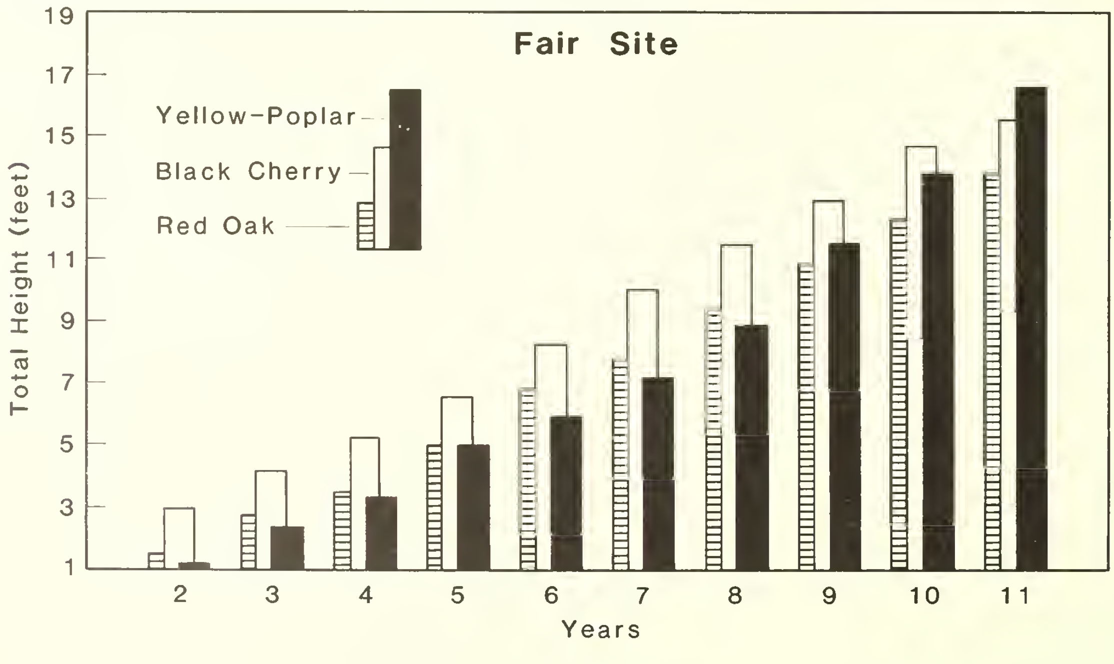
Good site. The initial length of clear bole was recorded 5 years after clearcutting. At that time, yellow-poplar and black cherry had a clear bole length of about 3.0 feet (to the first branch 1.0 inch in length or larger) while red oak averaged about 2.0 feet and sugar maple 1.0 foot. Twelve years after clearcutting, the clear bole length for yellow-poplar and black cherry was about 9.5 and 8.0 feet, respectively, while red oak was about 5.5 feet and sugar maple about 2.0 feet (Table 1). Thus, the yellow-poplar and black cherry were beginning to develop a clear bole, even though the study trees were continually released to a free-to-grow crown class. About 40 percent of the tree was in clear bole for yellow-poplar, black cherry, and red oak. For sugar maple it was 32 percent.

Fair site. The three species had a clear bole length of about 2.5 feet at the 5-year measurement period. After 11 years, the black cherry averaged 6.6 feet, red oak 6.2 feet, and yellow-poplar 5.7 feet of clear bole length (Table 1). Clear bole for red oak and black cherry averaged 45 and 43 percent of the total tree height, while for yellow-poplar, it averaged 35 percent. Yellow-poplar did not produce as high a percentage of clear bole length on the fair site as on the good site, but red oak increased its percentage of clear bole slightly on the fair site.

Discussion and Conclusions

This study suggests that free-to-grow yellow-poplars of seedling origin on a good site will be taller and larger in dbh than black cherry after 12 years of annual release. At this age, both species were taller and larger in dbh than red oak and sugar maple; the latter was shortest and had the smallest dbh of all species evaluated. From the time the trees were large enough to be measured at breast height, yellow-poplar had the largest diameter, followed by black cherry, and red oak (Fig. 1). Height growth showed a somewhat different pattern: For the

Figure 3.—Periodic total height response of free-to-grow yellow-poplar, black cherry, and red oak stems on a site with oak site index 62.



first 4 years, black cherry grew faster than the other species, but at 6 years the yellow-poplar trees were taller (Fig. 2). Height growth of red oak and sugar maple was less, with sugar maple growing the slowest.

The growth in dbh of the three species (yellow-poplar, black cherry, and red oak) studied on the fair site was about the same through the first 9 years. Yellow-poplar trees grew faster in diameter than black cherry, which outgrew the red oak. In height growth, the superiority of black cherry over yellow-poplar persisted through about the 8th year after clearcutting, with the yellow-poplar attaining a greater height by the 11th year (Fig. 3).

The data indicate that free-to-grow red oak seedlings are more competitive with the intolerant species on fair sites. This result was expected. The lack of response to release and the low survival rate of sugar maple seedlings on the good site indicates that small free-to-grow sugar maple stems on the ground when the stand is clearcut will not be competitive with other free-to-grow species (yellow-poplar, black cherry, red oak). A higher percentage of free-to-grow yellow-poplar and black cherry than of red oak will survive on the good sites. The survival rate of the free-to-grow red oak seedlings on the good site was disappointing.

For comparison with the annually released free-to-grow sapling stems, 9- and 12-year-old unreleased yellow-poplar and black cherry crop trees of seedling origin on a good red oak site were used (Trimble 1973). These data were the best available, but the unreleased trees were crop trees on a different site, selected from a population of faster growing trees.

For yellow-poplar, the growth response of the annually released trees was considerably higher than that of the unreleased dominant and codominant trees (Table 2). It appears that during the later years of the annual release study, the yellow-poplar trees were beginning to respond more rapidly to the release treatment. Annually released black cherry trees outgrew unreleased codominant black cherry trees but not the unreleased dominant black cherry.

Numerous local studies show that as hardwood stands develop into middle age, there will be some changes in the relative dbh growth rate of the different species (Trimble 1969; 1975). Red oak will become the fastest growing tree species, followed by yellow-poplar and black cherry. Little information is available on the relative height growth patterns of older trees of these species.

Free-to-grow yellow-poplars grew more in dbh and height on the good site than on the fair site. In general, the height growth of black cherry was better on the good site, but its dbh growth was only slightly better at best on the good site. Free-to-grow yellow-poplars were more sensitive to site differences at this early age than black cherry. However, height and dbh growth rates of red oak were about the same for the good and fair sites during the study period, suggesting that free-to-grow red oaks were too young to express site differences at this early age. Wendel (1975) reported that site quality did not affect the growth of 10-year-old red oak sprouts in West Virginia. Sprouts on a fair oak site grew in height at about the same rate as those on an excellent site. In another West Virginia study, height data for the tallest seedling and sprouts in 10-year-old clearcuts of different diameters indicated that at this early age, trees on the fair site were taller, on the average, than those on the better sites (Smith 1977).

The information in this paper can be used to evaluate early growth response of free-to-grow trees. Managers need information on other species and for longer times to understand the growth and development patterns of individual species.

Table 2.—Growth in dbh and total height of annually released, unreleased dominant, and unreleased codominant trees 9 and 12 years after clearcutting[1]

Species	9-Year		12-Year	
	Dbh	Total height	Dbh	Total height
	in	*ft*	*in*	*ft*
Yellow-poplar				
Released annually	1.6	17.4	3.0	28.4
Unreleased dominant	1.5	15.3	2.5	24.0
Unreleased codominant	1.1	13.6	1.8	20.5
Black cherry				
Released annually	1.1	15.3	1.8	21.5
Unreleased dominant	1.8	18.1	2.7	25.6
Unreleased codominant	1.1	14.3	1.4	19.2

[1]Data on unreleased trees from Trimble (1975); annual release data from Table 1.

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Smith, H. Clay. **Growth of Appalachian hardwoods kept free to grow from 2 to 12 years after clearcutting.** Res. Pap. NE-528. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 6 p.

Free-to-grow sapling-size yellow-poplars of seedling origin in young stands outgrew similar black cherry and red oak in both dbh and total height. Sugar maple did not respond to the free-to-grow treatment.

ODC 231.31:181.65:176.1

Keywords: Free-to-grow, Appalachian hardwoods, immature stands

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Comparison of Lumber Values for Grade-3 Hardwood Logs from Thinnings and Mature Stands

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Abstract

The value per M bf (thousand board feet) of the lumber sawed from Grade-3 logs, 8 to 11 inches in diameter, from thinnings was compared with that from a harvest of mature-stand cut. The species tested were red oak (*Quercus rubra* L.), yellow-poplar (*Liriodendron tulipifera* L.), and hard maple (*Acer saccharum* Marsh). The total lumber value for each species was greater for logs obtained from thinnings. The value per M bf of the lumber sawed from red oak and yellow-poplar logs from thinnings was significantly higher than that from mature stands.

Introduction

Several million acres of 40- to 60-year-old hardwood stands in the Northeast need thinning to improve crop-tree spacing and species composition. Past studies have shown that prescribed thinning of these stands yields from 2 to 4 M bf (thousand board feet) per acre of sawable bolts and logs (Craft and Baumgras 1978). Because most of the trees cut are small, the sawlogs recovered are predominantly Factory Grade 3 quality (Rast et al. 1973). But since most of the sawlogs are butt logs, the yield of No. 1 Common and Better lumber would be expected to exceed yields from Grade-3 logs recovered in harvest cuttings. This should make the lumber-value yields for Grade-3 logs from thinnings greater than yields for Grade-3 logs from mature stands. To test this hypothesis, we compared actual lumber-value yields from Grade-3 logs from thinnings and mature stands. Three species, yellow-poplar (*Liriodendron tulipifera* L.), red oak (*Quercus rubra* L.), and hard maple (*Acer saccharum* Marsh), were studied.

The Study

Sample-Log Selection

Factory Grade-3 logs were obtained from three tracts of upland hardwood timber. Sample logs from thinnings were from overstocked stands on both the Camp Creek State Forest and the Monongahela National Forest in West Virginia. The logs from mature stands were obtained from Georgia Pacific Corporation during a sawtimber harvesting operation on company land near Rainelle, West Virginia. All sample logs were obtained from stands with Site Class 70 to 80 for red oak.

During the thinning operation, tree length stems were skidded to a landing where they were bucked to produce the highest grade logs. Study logs were selected by taking the first five Grade-3 logs in each diameter class (8, 9, 10, 11) that were bucked at the landing.

The logs from mature stands were obtained in the order that they were bucked from full-length stems, and matched with the thinning sample by diameter class and length. All logs were hauled to our laboratory for processing.

Processing

All sample logs were scaled, numbered, and grade sawed into 4/4 lumber. The lumber from each log was graded by National Hardwood Lumber Association (NHLA) rules (National Hardwood Lumber Association 1982) and tallied separately. Lumber-grade yields for Grade-3 logs from thinnings (Table 1) and mature stands (Table 2) were tallied by species and grades. A further breakdown of the lumber yields by diameter class is shown in Tables 3, 4, and 5.

The value of lumber for each species (by log source) was determined by applying prices, by grade, to the appropriate volume yields. Prices (Table 6) used to establish these values of No. 2 Common and Better grades were from the October 3, 1981, edition of the *Hardwood Market Report*. Prices for 3A and 3B Common lumber were based on values obtained from several sawmill operators. Analysis of variance was used to test for differences in total value per M bf for logs from thinnings versus those from mature stands.

Table 1.—Lumber-grade yields for Grade-3 logs from thinnings, in board feet

Species	Net Int. ¼-inch log scale	Lumber tally	NHLA lumber-grade yields							
			FAS	1F	1C	2C	2A	2B	3A	3B
Red oak	555	696	21 (3.0)[a]	27 (3.9)	162 (23.3)	278 (39.9)	—	—	170 (24.4)	38 (5.5)
Hard maple	691	775	—	16 (2.1)	132 (17.0)	336 (43.4)	—	—	262 (33.8)	29 (3.7)
Yellow-poplar	642	769	20 (2.6)	10 (1.3)	86 (11.2)	—	322 (41.9)	216 (28.1)	107 (13.9)	8 (1.0)

[a]Percent in parentheses; totals may not equal 100 due to rounding.

Table 2.—Lumber-grade yields for Grade-3 logs from mature stands, in board feet

Species	Net Int. ¼-inch log scale	Lumber tally	NHLA lumber-grade yields							
			FAS	1F	1C	2C	2A	2B	3A	3B
Red oak	562	639	11 (1.7)[a]	—	86 (13.5)	324 (50.7)	—	—	218 (34.1)	—
Hard maple	662	740	13 (1.8)	—	91 (12.3)	378 (51.1)	—	—	244 (33.0)	14 (1.9)
Yellow-poplar	648	746	—	—	34 (4.6)	—	263 (35.3)	305 (40.9)	99 (13.3)	45 (6.0)

[a]Percent in parentheses; totals may not equal 100 due to rounding.

Table 3.—Lumber-grade yield by diameter class from red oak logs by harvest type, in board feet

Diameter class (inches)	Harvest type	Net Int. ¼-inch log scale	Lumber tally	NHLA lumber-grade yields					
				FAS	1F	1C	2C	3A	3B
8	Thinning	86	137	—	13	11	68	40	5
	Mature	88	101	—	—	5	47	49	—
9	Thinning	115	129	—	—	37	56	36	—
	Mature	111	127	—	—	13	52	62	—
10	Thinning	154	194	—	4	47	78	42	23
	Mature	165	184	—	—	37	80	67	—
11	Thinning	200	236	21	10	67	76	52	10
	Mature	198	227	11	—	31	145	40	—

Table 4.—Lumber-grade yield by diameter class from hard maple logs by harvest type, in board feet

Diameter class (inches)	Harvest type	Net Int. ¼-inch log scale	Lumber tally	NHLA lumber-grade yields					
				FAS	1F	1C	2C	3A	3B
8	Thinning	116	137	—	—	14	72	48	3
	Mature	109	138	—	—	16	81	41	—
9	Thinning	155	169	—	—	30	67	69	3
	Mature	147	152	—	—	30	74	48	—
10	Thinning	200	210	—	5	34	68	80	23
	Mature	191	211	7	—	15	93	96	—
11	Thinning	220	259	—	11	54	129	65	—
	Mature	215	239	6	—	30	130	59	14

Table 5.—Lumber-grade yield by diameter class from yellow-poplar logs by harvest type, in board feet

Diameter class (inches)	Harvest type	Net Int. ¼-inch log scale	Lumber tally	NHLA lumber-grade yields						
				FAS	1F	1C	2A	2B	3A	3B
8	Thinning	95	131	—	—	—	33	75	23	—
	Mature	101	130	—	—	—	33	87	10	—
9	Thinning	134	145	4	5	15	44	45	24	8
	Mature	135	177	—	—	14	55	73	35	—
10	Thinning	183	223	6	5	30	119	47	16	—
	Mature	180	200	—	—	15	88	71	26	—
11	Thinning	230	270	10	—	41	126	49	44	—
	Mature	232	239	—	—	5	87	74	28	45

Table 6.—Prices by grade and species, in dollars per M bf

Grade	Poplar	Red oak	Hard maple
FAS	420	540	430
1F	410	530	420
1C	283	400	340
2C	—	159	215
2A	175	—	—
2B	157	—	—
3A[a]	110	139	180
3B[a]	110	110	110

[a]Obtained from sawmill operators.

Results

The lumber value per M bf from Grade-3 logs from thinnings and mature stands was significantly different at or above the 90-percent level for red oak and yellow-poplar. For red oak, the lumber value per M bf for logs from thinnings was significantly higher than that for logs from mature stands at the 99-percent level. For hard maple, there was no significant difference in lumber values per M bf. However, the average lumber value per M bf for logs from thinnings was greater than that for logs from the mature stands in all species sampled (Table 7).

All of the logs from the mature stand were uppers, while the thinning operation yielded 28 butt logs and 32 upper logs.

Conclusions

Within the 8- to 11-inch-diameter classes, lumber cut from Grade-3 red oak and yellow-poplar logs obtained from thinnings yields a significantly higher value than similar logs harvested from a mature stand. For Grade-3 hard maple logs in the same diameter-class range, little difference in lumber values occurs in logs from the two sources. Thus, for red oak and yellow-poplar, sawmills should be able to use a higher proportion of Grade-3 logs from thinnings than Grade-3 logs from mature-stand harvests.

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Table 7.—Average lumber value by diameter class, species, and source, in dollars per M bf

Diameter class	Red oak		Hard maple		Yellow-poplar		All species	
	Thinning	Mature	Thinning	Mature	Thinning	Mature	Thinning	Mature
8	197.76	156.73	212.21	218.90	153.89	158.94	187.95	177.96
9	219.61	173.87	220.45	216.08	180.05	160.24	206.70	183.40
10	218.76	198.61	216.50	216.69	194.81	168.02	210.02	194.44
11	274.08	206.01	238.78	217.46	193.39	153.98	235.41	192.48
All diameters	227.55	183.81	221.98	217.28	180.54	160.12	210.02	187.07

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Emanuel, David M. **Comparison of lumber values for Grade-3 hardwood logs from thinnings and mature stands.** Res. Pap. NE-529. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 4 p.

The lumber value per M bf (thousand board feet) by species (red oak, yellow-poplar, and hard maple) obtained from Grade-3 logs from a thinning cut was higher than that from a mature-stand harvest operation. Red oak and yellow-poplar lumber values per M bf were significantly higher.

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Keywords: Product yields; hardwood thinnings

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1983

Ground Cover Changes Resulting from Low-Level Camping Stress on a Remote Site

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Abstract

This study reports the effects of low-level camping stress on vegetation in a remote site. South Big Garden Island in Penobscot Bay, Maine, was studied because (1) it had no prior recreational use; thus, comprehensive base line data could be obtained; and (2) the exact number of campers could be monitored throughout the study period. The continuous line-intercept method based on a single vegetation transect line was developed to monitor vegetation and ground cover changes over a 2-year-period. The low-level use (an average of 50 campers/year) that was recorded did not significantly reduce the total vegetation cover but did have an effect on species composition.

Acknowledgment

The logistic assistance of the Hurricane Island Outward Bound School of Rockland Maine and the Maine Chapter of the Nature Conservancy is gratefully acknowledged.

Introduction

Many public and private land managers have encouraged the development of designated dispersed campsites (unimproved remote sites at least 200 feet from trails and sources of water), both to satisfy a growing number of users who prefer solitude and to relieve pressure on other intensively used recreation areas (Canon et al. 1979; Leonard et al. 1980). As interest in dispersed recreation continues to increase, it is desirable to evaluate the ecological effects of backcountry camping and hiking before the establishment of use patterns. These use patterns can be difficult or expensive to modify if they are found to have adverse effects on plant and soil communities. To evaluate the effects of such use, however, managers and landowners need "hard" information that either prescribes specific use levels for a given set of ecological conditions, or is able to predict changes in vegetation cover for given use loads. With such information in hand, managers will have the tools to understand the options available in a given set of circumstances and the likely consequences of their management decisions.

To conduct recreation research that ties specific use levels to specific ecological effects, researchers need to study areas that have little prior recreational use so they can gather base line information before camping and hiking take place. It is difficult to locate alpine camping areas in the East that do not have a history of prior use; so, we studied islands in the Northeast that are now in the low-level stages of use with attendant stress from camping activity (Gerber 1980). We expect that the results of these island studies will also be useful to backcountry alpine managers because of the similarity of plant communities and growing conditions (Hill 1919; 1923).

Study Area

In June of 1980, a low-use camping study was initiated on South Big Garden Island, which is part of the Nature Conservancy's White Island Preserve—a small group of islands approximately 1 mile west of Vinalhaven in Penobscot Bay, Maine. The location and conditions of the study differed from previous studies in two important aspects. First, most studies of camping impact and ground cover changes (LaPage 1967; Monti and Mackintosh 1979; Cole 1981), have initiated measurements without comprehensive base line information on the kind and distribution of plant species before use. On South Big Garden, measurements were taken in an area that was undisturbed by prior recreational use. Second, in previous studies, use levels generally have been estimated, but in our study, precise numbers of campers were introduced to the study site on given dates through the cooperation of the Hurricane Island Outward Bound School.

The site was selected because it has physical boundaries of granite outcrops that effectively limit camping to the relatively small area where measurements were collected. The island is characterized by generally shallow soils that, for the most part, consist of organic material covering these granite ledges. The study plot itself is a 10-m by 16-m flat area underlain by a pocket of glacial till generally suited for camping. Sloping granite ledges running along either side of the study area begin at the sandy beach landing site and taper into each other at the inland end of the study site. The spruce trees on the site are well spaced with a relatively open canopy. Ground cover before use consisted of: moss, duff, lichens, grass, and a mixture of herbaceous and woody plants, including in order of dominance: *Rubus, Aster, Trientalis, Maianthemum, Solidago, Viburnum, Viola, Ribes*, and *Fragaria*. The Outward Bound students camped here because it was the only suitable camping area on this portion of the island.

All camping by the students consisted of overnight stays of 7 to 12 persons per visit. In the summer of 1980, a total of 29 students camped on South Big Garden in the course of three visits. In 1981, 58 students camped on the island during six visits; and in 1982, 12 students camped overnight. The dates that camping occurred, the number of users, and the measurement schedule are shown in Table 1.

Table 1.—Use and measurement record

Date of use	Number of users	Measurement date
		06/10/80
06/14/80	12	
06/27/80	10	
06/31/80	7	
		08/25/80
05/26/81	8	
06/17/81	10	
06/24/81	8	
07/16/81	11	
		07/28/81
08/16/81	10	
		09/04/81
09/17/81	11	
09/22/81	12	
TOTAL:	99	06/04/82

Methods

A vegetation transect line was established and permanently located by nailing numbered tags to the bases of two reference trees. This transect extended beyond the length of the camping area to 26.2 m. The main transect forms the basis for the continuous line-intercept system developed by Leonard and McBride (1981). This system has three parts: (1) continuous sampling along the main transect; (2) continuous sampling along perpendicular transects; and (3) recording of individual plants.

Sampling along the main transect was accomplished by recording the distance along the transect to the nearest .05 m that each species or cover category intercepted the line. Each cover type was listed in order of dominance or greatest percentage of cover. Broad categories such as mossmat, duff, exposed organic soil, and specific herbs were used when describing ground cover.

Perpendicular transects were placed every half meter along the main transect. The length of the perpendiculars varied with the width of the study plot, but did not extend beyond 4 m on either side of the main transect. Ground cover was measured the same way along these perpendiculars as on the main transect. Perpendicular transects off the main transect meant that only one permanent transect needed to be established across the study plot.

Individual plants such as woody seedlings or single occurrences of forb species within 4 m on either side of the main transect were recorded. The positions of such plants were measured with a tape perpendicular to the corresponding point on the main transect line.

Analysis of Data

The data collected with this line-intercept system were tabulated for the center line, which was 26.2 m in length. Since camping impact did not extend beyond 16 m, tabulations included data only up to that point. From the line-intercept readings, vegetation categories were listed in order of dominance. For example, if a given sample point lists moss, duff, and grass, moss is the most dominant cover type, duff is second, and grass is third in dominance. Since we are primarily interested in the relative changes in percentage of cover of the various vegetation categories and of duff, we assigned percentages to each order of dominance in the following manner for analysis:

Order of dominance		
1	*2*	*3*
Percent		
100	—	—
60	40	—
60	35	05

While given sample points measured in the field may have differed by a few percentage points from the dominance categories shown above, we believe that the average of all sample points along the center line correspond closely to this idealized scheme used for analysis. For analysis, moss and lichens were sampled as mosses, and all herbs were included in one category.

Percentage of interception was calculated by multiplying the dominance percentages by a measured interval along the center line and dividing by the total length of the transect. For example, if moss occurs in the first order of dominance along 10 m of the center line, its percentage of interception was calculated as 10 m × 0.6 ÷ 16 m, or 37.5. Similarly, if grass occurs in the third order of dominance along 8 m of the center line, we calculated the percentage of interception of grass on the study site as 8 m × 0.05 ÷ 16 m, or 3. The calculations used in the second order of dominance depended on whether the field readings recorded two or three vegetation categories.

Results and Discussion

The results of converting the order of dominance field readings to percentage of interception of the center line for the South Big Garden study site are presented in Table 2.

The largest changes in ground cover area over the course of the study occurred in the moss category. Before camping, mosses comprised between one-third and one-half of the area (41.3 percent), but this percentage steadily decreased over the 2-year period in each of the five measurements. The consistent decline in moss cover over the period strongly indicates the susceptibility of mosses and lichens to camping stress.

It might be expected that the decrease in moss cover could have resulted in a corresponding increase in the duff category. Although the percent of duff cover did rise from 32.3 percent to 41.6 percent along the center line from the beginning to the end of the study, it seems that the elimination of mosses results only in an increase of unvegetated duff areas. Both herbs and grasses occupied some of the area formerly covered by mosses. The largest increase in the duff cover was recorded during the middle of the second season of measurement on July 28, 1981, when the cumulative number of users was 66. Thereafter, the total duff cover decreased while both herb and grass covers increased.

At the beginning of the study, grass cover formed a rather insignificant 11.9 percent of the total cover on the plot. It increased its percentage of interception on the center line through the next three measurements, and it reached 31.0, or approximately one-third of the cover, by September 4, 1981.

We hypothesize that the grasses, though on a relatively marginal site for luxuriant growth, are able to increase at the expense of mosses during camping because of the ability to sprout from underground stems or rhizomes. That is, where grasses are found growing (1) in an undisturbed condition, (2) in association with a moss-lichen mat, and (3) in a relatively open spruce woods, they are not very vigorous and do not cover a significant percent of the area. However, after some stress such as camping, which significantly reduces the moss mat, the grasses not only persist, but also increase occupation of the site through the extension of underground stems. At the last measurement date (June 4, 1982), the grasses seemed to be slightly less prevalent at the South Big Garden camping site. We do not know whether this finding is due to their retreating to a presence close to the base line condition or due to the fact that they have not yet fully developed at this point in the season. The general trend with grasses on this site indicates that they can react favorably to trampling as a result of camping stress and that they survive better than mosses when subjected to the same stress.

Table 2.—Percentage of interception on center line shows ground cover changes resulting from camping activities on a remote site

Ground cover	Measurement date				
	06/10/80	08/25/80	07/28/81	09/04/81	06/04/82
Moss	41.3	29.4	16.1	12.9	11.6
Duff	32.3	42.9	49.1	42.6	41.6
Grass	11.9	16.1	20.3	31.0	20.6
Herbs	14.2	8.4	13.8	12.3	26.1
Cumulative number of users to date	0	29	66	76	99

The herbs reacted somewhat differently from both the mosses and grasses. After part of a season's camping stress, they initially decreased in area coverage from 14.2 percent before use to 8.4 percent on August 25, 1980. However, after the August 1980 measurement, they began to increase again until they comprised 26.1 percent of the area coverage on the last measurement date.

We hypothesize that the scarification of the soil surface under the spruce canopy provides a more favorable seedbed for annuals like *Maianthemum*, *Trientalis*, *Solidago,* and *Aster* and allows these species to increase their presence on a site subject to low-level camping stress. We would expect the annual herbs on the South Big Garden site to continue to occupy a significant portion of the area formerly covered by mosses until the mosses recover some of their original area. If moss cover increases in the absence of further disturbance, probably the herb cover would begin to decrease since a moss-lichen mat would seem to be a less favorable seedbed for annually flowering herbs than duff disturbed by low-level camping stress.

Conclusion

With a cumulative number of users approximating 100 over a 2-year period on a remote camping site, substantial changes in relative area coverage of four ground cover conditions did not occur. The greatest changes on the site probably occurred on the trail leading up from the landing site to the camping site. Mosses and lichens are examples of species of plants that are susceptible to damage and do not readily recover. However, both grasses and herbs are able to occupy most of the area previously occupied by mosses. Grasses appear to be able to increase by sprouting from underground stems, while herbs appear to benefit from the scarified seedbed that results from trampling during camping stress.

Although mosses did decrease over the course of the study and herbs initially declined before rebounding, we conclude that camping levels of 100 people over two seasons, when confined to groups averaging 10 persons per visit, did not have a deleterious effect on the vegetation of South Big Garden Island in Penobscot Bay. We estimate that the relative conditions we initially encountered will return to their precamping levels within a single growing season.

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Leonard, R. E.; McBride, J. M.; Conkling, P. W.; McMahon, J. L. **Ground cover changes resulting from low-level camping stress on a remote site.** Res. Pap. NE-530. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 4 p.

Reports the effects of low-level camping stress on vegetation in a remote site. South Big Garden Island in Penobscot Bay, Maine, was studied because (1) it had no prior recreational use; thus, comprehensive base line data could be obtained; and (2) the exact number of campers could be monitored throughout the study period. The continuous line-intercept method based on a single vegetation transect line was developed to monitor vegetation and ground cover changes over a 2-year period. The low-level use (an average of 50 campers/year) that was recorded did not significantly reduce the total vegetation cover but did have an effect on species composition.

Keywords: camping; low impact; vegetation impacts; trampiing

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Research Paper NE-531

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Predicting Diameters Inside Bark for 10 Important Hardwood Species

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Everette D. Rast
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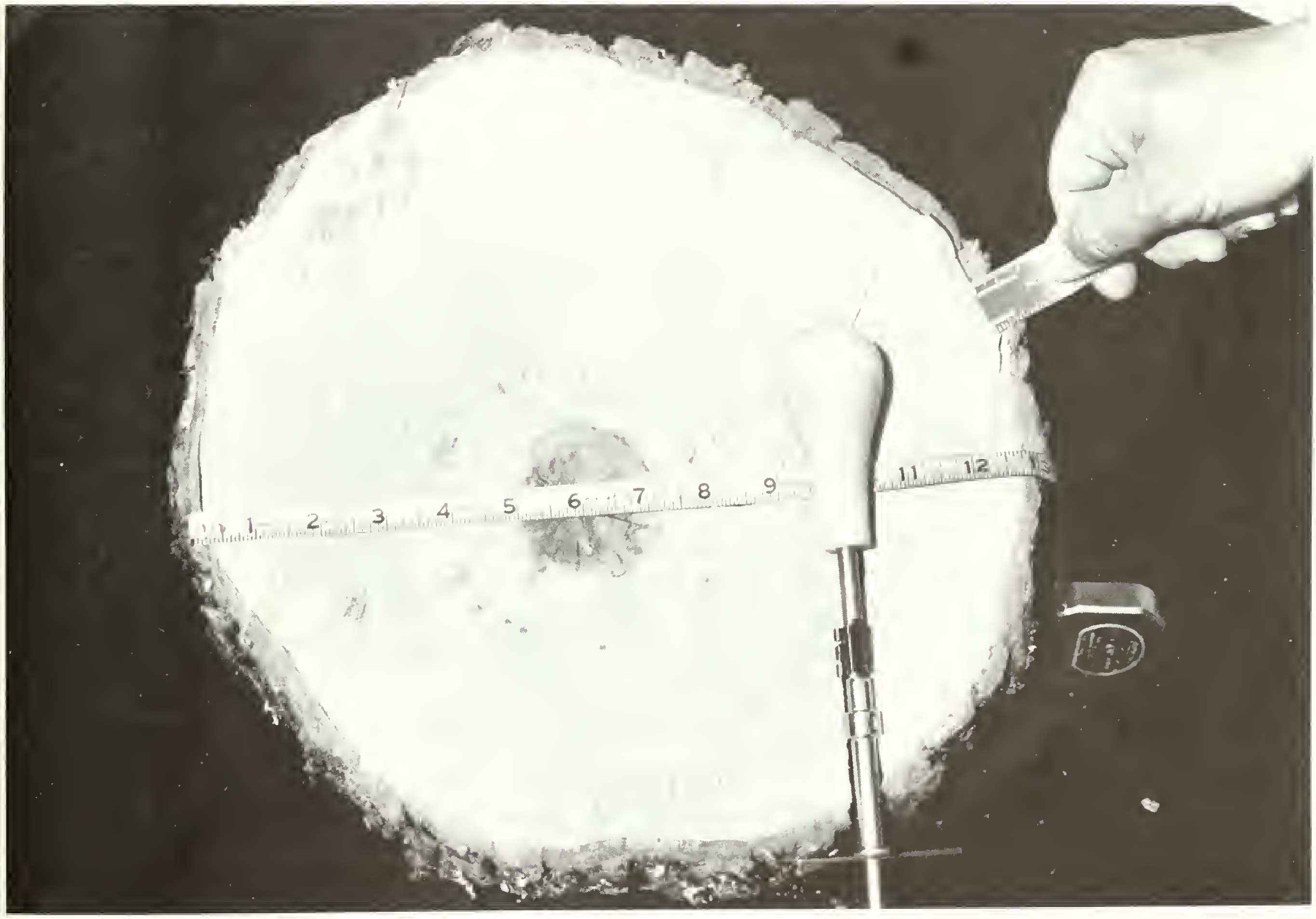

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Abstract

General models for predicting DIB/DOB ratios up the stem, applicable over wide geographic areas, have been developed for 10 important hardwood species. Results indicate that the ratios either decrease or remain constant up the stem. Methods for adjusting the general models to local conditions are presented. The prediction models can be used in conjunction with optical dendrometer measurements or stem taper equations to convert outside bark diameters to inside bark diameters.

Upper stem diameters measured outside bark (DOB) with an optical dendrometer, or estimated with a stem taper equation, must be converted to diameters inside bark (DIB) to determine the volume of wood alone. Meyer (1946) developed mean DIB/DOB ratios at breast height for several hardwood species in Pennsylvania, but suggested that further experimentation was warranted to determine if the ratios changed up the stem. Koch (1971) investigated the bark volume of five commercial hardwood species in West Virginia and found that the DIB/DOB ratios did in fact change up the stem for trees 4-6 inches dbh. DIB/DOB ratios were essentially constant above a height of 10 feet for larger trees.

Recently, the most common way to convert DOBs to DIBs has been with the three options suggested by Grosenbaugh (1964) for his STX programs. The three options are fitted to sample data via linear or nonlinear least squares procedures, and the option with the best fit is selected as the model to predict DIB from DOB, DBHOB, and DBHIB. The three options are:

Option 1: $DIB = DOB * (DBHIB/DBHOB)$

Option 2: $DIB = DOB * (1 - (1 - DBHIB/DBHOB) * (QUAN/(DENO - DOB/DBHOB)))$

Option 3: $DIB = DOB * (DBHIB/DBHOB) * (QUAN/(DENO - DOB/DBHOB))$

where DBHOB = diameter breast height outside bark, DBHIB = diameter breast height inside bark, and QUAN and DENO are names assigned by Grosenbaugh to model parameters to be estimated in Options 2 and 3. The DIB/DOB ratio is assumed to be constant up the stem in Option 1, increase curvilinearly up the stem in Option 2, and decrease curvilinearly up the stem in Option 3 (Boehmer and Rennie 1976). Grosenbaugh recommended values of 1.0 and 2.0 for QUAN and DENO in Option 2, and 9.0 and 10.0 in Option 3. Local values for QUAN and DENO can be estimated with nonlinear least squares techniques with the constraint that QUAN = (DENO − 1.0) (Brickell 1970).

Mesavage (1969) found that Option 2 proved best for southern pines. Results for hardwoods have indicated that either Option 1 or 3 is appropriate, depending on the species. Wiant and Koch (1974) found that Option 1 performed best for five hardwood species measured in West Virginia. Option 3 was found to be the best overall predictor of DIB for hardwood species in Tennessee when local values of QUAN and DENO were used, but Option 1 performed as well on some species (Boehmer and Rennie 1976). Further investigations by Colaninno et al. (1977) revealed that either Option 1 or 3 was best, depending on the species, for seven hardwood species in northern West Virginia.

General models for predicting DIB/DOB ratios up the stem, applicable over wide geographic areas, are developed in this paper for 10 important hardwood species. Methods for adjusting the models to local conditions are also discussed. While we continue to advocate the use of Grosenbaugh's three options, our data set lacked the necessary bark thickness reading at DBH, so we had to use an entirely new mathematical approach.

Data

The data used in this study were originally collected during the 1960s in conjunction with the development of log and tree grades for hardwoods. A total of 1619 trees were used to develop the DIB/DOB ratios for the 10 hardwood species (Table 1). Scientific names of all species referred to in this study can be found in Little (1978). Most species were sampled in at least two states.

DBHOB was measured to the nearest 0.1 inch on each standing tree. After felling, the trees were bucked into 8- to 16-foot logs, the length of each log being determined by such factors as crook, sweep, and rot. DIB and bark thickness were measured to the nearest 0.1 inch at the small end of each log with a ruler. Two DIB's measured at right angles to each other were averaged to obtain the DIB reading, and four bark thickness readings measured at right angles to each other were averaged to obtain the bark thickness reading. All trees had at least two DIB and bark thickness readings; one tree had seven. Bark thickness was *not* measured at DBH.

Methods

Inspection of the three options listed previously reveals that the DBHIB/DBHOB ratio is needed to determine which option fits the sample data best, and to determine local values for QUAN and DENO. Since the data used in this study lacked the DBHIB/DBHOB ratio, a mathematical model that approximated the three options had to be developed.

DIB/DOB is plotted over DOB/DBHOB for each of the three options in Figure 1 for a tree that has a DBHIB/DBHOB ratio of 0.91. Option 3 is also plotted using DENO = 22.62, a local value for white oak developed by Boehmer and Rennie (1976). Similar shaped lines result for trees with different DBHIB/DBHOB ratios. It is evident from Figure 1 that option 3 can be very closely approximated by the linear relationship between DIB/DOB and DOB/DBHOB. That is,

$$DIB/DOB = \beta_0 + \beta_1 (DOB/DBHOB), \quad \text{(Model 1)}$$

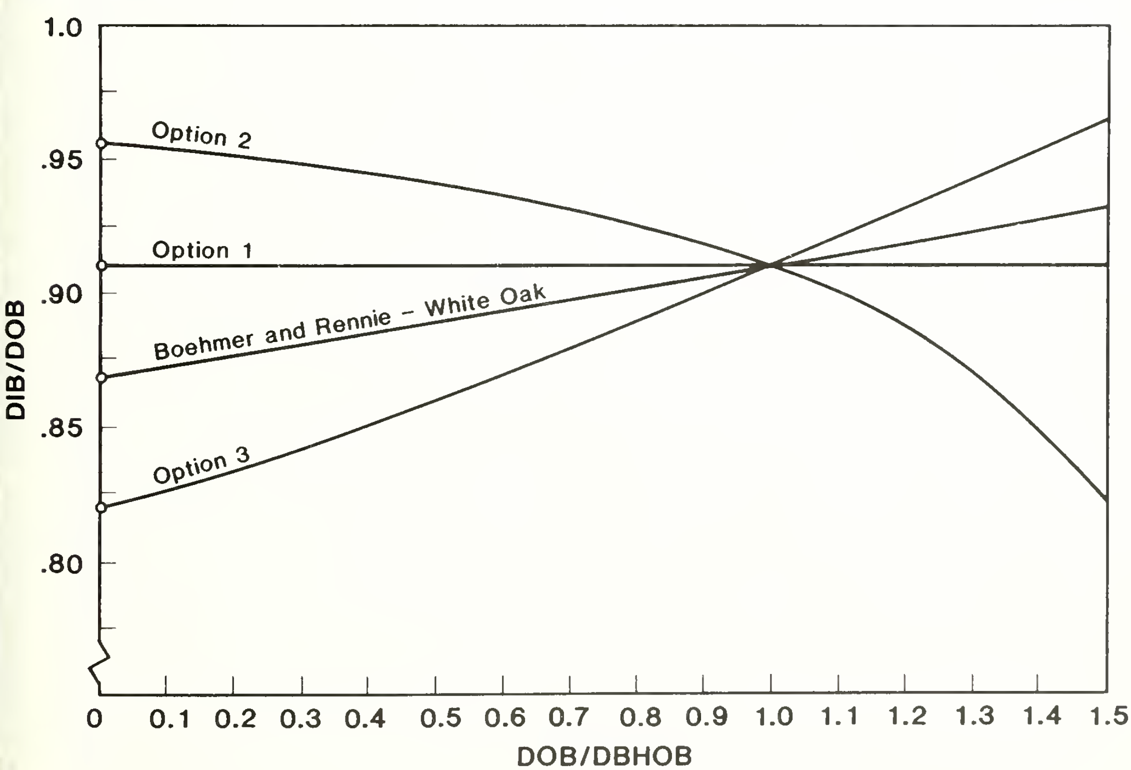
Table 1.—Summary characteristics of data used to develop DIB/DOB ratios.

Species	Location	Number of trees	DBH Minimum-Mean-Maximum		
			Inches		
Chestnut oak	OH, GA, TN, WV, VA	347	11.0	19.8	48.0
Red maple	WV, VT, PA, MI	266	10.5	16.6	33.1
Northern red oak	GA, NC, TN, WV, VA	212	11.7	24.4	38.2
White oak	KY, GA, NC, TN	205	10.3	20.5	35.7
Sugar maple	WV, VT, MI, NH	163	11.3	20.7	29.7
Black oak	GA, NC, TN, VA	159	12.2	21.5	33.8
Yellow-poplar	VA, AL	159	11.4	19.2	32.1
Black cherry	WV, PA	53	11.9	19.3	28.1
Southern red oak	TN	29	13.2	19.1	26.8
American beech	WV	26	12.9	18.4	29.9

for DBHOB and DOB greater than zero. The linear relationship would not as closely approximate Option 2, but Option 2 has not been found to be the best predictor for hardwoods. Model 1 can be fitted to sample tree data to determine the *trend* in the DIB/DOB ratios up the stem even if the DBHIB/DBHOB ratio is not known for each sample tree. If β_1 (estimated from sample data) is not significantly different from zero, then a trend the same as Option 1 would result. If β_1 is positive, trends similar to Option 3 would result, and if β_1 is negative, trends similar to Option 2 would result. The estimated DIB/DOB ratios would still remain constant, increase curvilinearly, or decrease curvilinearly up the stem because the DOB/DBHOB ratio is not a linear function of increasing tree height. The predicted DBHIB/DBHOB ratio from Model 1 would be the DIB/DOB ratio estimated when DOB/DBHOB equals one. That is, the predicted DBHIB/DBHOB ratio equals $\beta_0 + \beta_1$. As discussed later, Model 1 can also be adjusted for application to pass through known DBHIB/DBHOB points.

Since the DIB/DOB ratios measured on the same tree are correlated observations, estimates of the coefficients for Model 1, β_0 and β_1, were determined individually for each tree. The sample estimates of the coefficients were then averaged to determine mean values for each species. A multivariate regression analysis was used to determine whether DBHOB had a significant effect on the β's for a given species. The hypothesis $\beta_1 = 0$ was then tested. If β_1 was not significantly different from zero, all DIB/DOB ratios measured for that species were pooled and averaged to obtain a constant DIB/DOB ratio.

Figure 1.—DIB/DOB ratios for Grosenbaugh's three options and Boehmer and Rennie's model for white oak. Based on a tree with DBHIB/DBHOB = 0.91.



Results

Estimates of β_0 and β_1 for the ten species groups are shown in Table 2. DBHOB did not have a significant effect ($\alpha = .01$) on the β's for any of the species groups. Even though the DBHOB effect was not significant, users should be reminded that mostly larger trees were analyzed in this study. Since β_1 was not significantly different from zero for cherry, southern red oak, or beech, the constant DIB/DOB ratio listed in Table 1 is recommended for these species instead of using the β's.

Results of this study are consistent with other studies for hardwoods in view of the fact that the DIB/DOB ratios were found to either remain constant or decrease up the stem. In particular, the results coincide closely with those found by Boehmer and Rennie (1976). They found that Option 3 was the best for white oak and yellow-poplar if local values of QUAN and DENO were used. Fitting Model 1 to sample data closely parallels fitting local values of QUAN and DENO for Option 3. They also found that Option 1 was as good as Option 3 for southern red oak.

Adjusting Model 1 to Local Conditions

Estimates of β_0 and β_1 listed in Table 2 are applicable over a wide geographic area. However, we highly recommend that the estimates be adjusted to local conditions prior to application.

A sample data set consisting of 92 white oak trees from one location in north-central Kentucky is used to demonstrate adjustments to Model 1. DBHOB ranged from 5.1 inches to 18.2 inches. Two to nine DIB/DOB measurements up the stem, including DBHIB/DBHOB, were recorded for each tree. Test data that included the DBHIB/DBHOB ratio were not available for the other species groups.

The DIB/DOB ratios are plotted over DOB/DBHOB in Figure 2. The decreasing trend of the ratios up the stem is clearly evident. Model 1,

$$\text{DIB/DOB} = 0.881 + 0.056\ \text{DOB/DBHOB} \quad \text{(Model 1)}$$

is plotted on the graph. While the slope parameter, 0.056, closely approximates that of the sample data, the intercept parameter, 0.881, is clearly too high. Since the DBHIB/DBHOB ratios are known for the sample data, they can be used to adjust Model 1. Adjustments can be made on a stand basis using a sample of the DBHIB/DBHOB ratios, or on an individual tree basis using each DBHIB/DBHOB ratio. In practice, adjustment on a stand basis would probably be more common, but if the DBHIB/DBHOB ratio is known for each tree, as may be the case for studies or sampling schemes utilizing an optical dendrometer, adjustments should be made on a per tree basis. Adjustments are made only on the intercept parameter, β_0. Upper stem DIB/DOB ratios needed to adjust the slope parameter, β_1, are seldom measured in the field. If they are, the best approach then would be to fit completely new parameters to Model 1, or determine which of the options suggested by Grosenbaugh is best.

In order to adjust Model 1 on a stand basis, a random sample of 9 trees (an approximate 10 percent

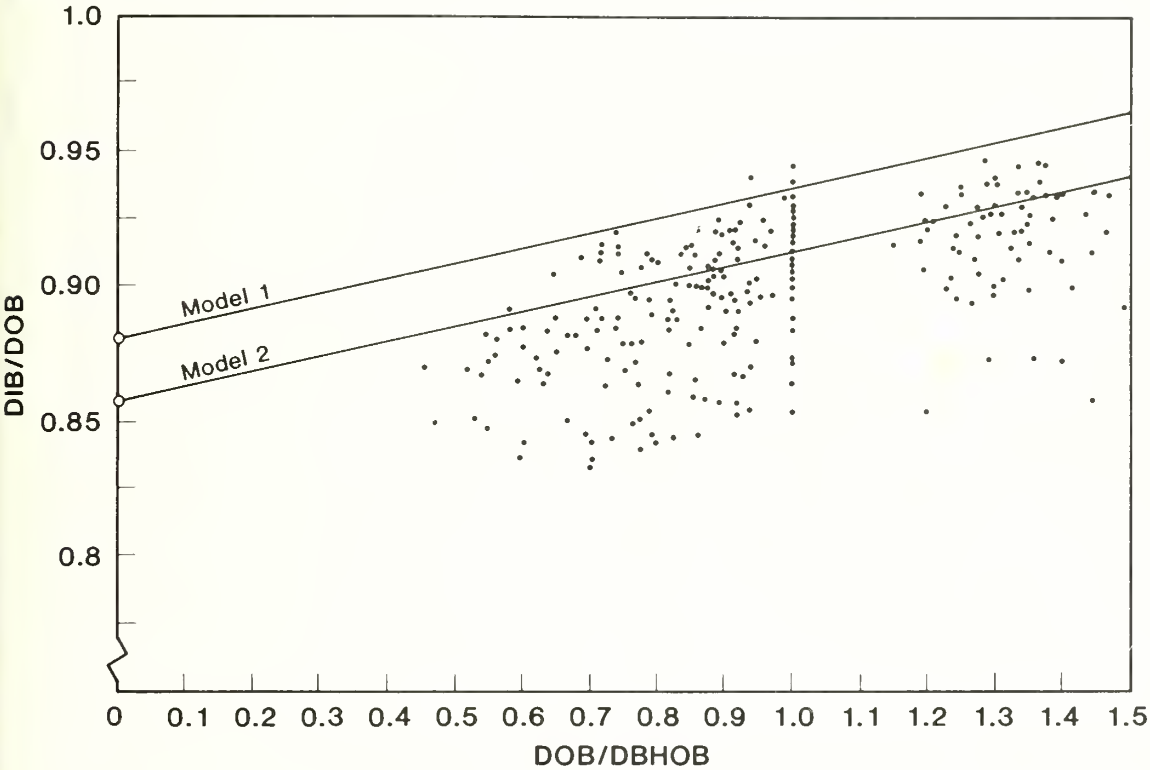
Table 2.—Estimated values of β_0 and β_1 for ten hardwood species groups.

Species	β_0	Standard error, β_0	β_1	Standard error, β_1	H_0:[a] $\beta_1 = 0$	Mean[b] DIB/DOB
Chestnut oak	0.774	0.008	0.149	0.011	**	—
Red maple	.919	.005	.045	.006	**	—
Northern red oak	.864	.007	.084	.010	**	—
White oak	.881	.009	.056	.011	**	—
Sugar maple	.873	.013	.060	.017	**	—
Black oak	.832	.011	.103	.015	**	—
Yellow-poplar	.840	.008	.087	.011	**	—
Black cherry	.934	.009	.017	.012	N.S.	0.947
Southern red oak	.888	.024	.040	.033	N.S.	.916
American beech	.931	.022	.035	.025	N.S.	.961

[a]N.S. = not significant, ** = significant at $\alpha = .01$ level.

[b]Calculated for use only if β_1 not significantly different from zero.

Figure 2.—DIB/DOB ratios for 92 white oak sample trees.



sample) was drawn from the 92 trees. The mean DBHIB/DBHOB ratio for the nine randomly-selected trees was 0.913. Since the predicted DBHIB/DBHOB using Model 1 was $(\beta_0 + \beta_1) = 0.937$, the regression line must be "shifted" down to pass through the point (1, 0.913). The adjusted model becomes

$$\text{DIB/DOB} = \beta_0^* + 0.056 \text{ DOB/DBHOB}, \quad \text{(Model 2)}$$

where

$$\begin{aligned}\beta_0^* &= (\text{Mean DBHIB/DBHOB ratio}) - (\beta_0 + \beta_1) + \beta_0 \\ &= (\text{Mean DBHIB/DBHOB ratio}) - \beta_1 \\ &= 0.913 - 0.056 = 0.857.\end{aligned}$$

Model 2 is also plotted in Figure 2. The adjusted model passes through the mean DBHIB/DBHOB ratio of the sample trees, 0.913, when DOB = DBHOB, and also provides a better fit to all data points.

When DBHIB/DBHOB ratio is known for each tree, Model 1 can be adjusted to pass through the point (1, DBHIB/DBHOB) for each tree. The adjusted model for each tree then becomes

$$\text{DIB/DOB} = \beta_0^{**} + \beta_1 \text{ DOB/DBHOB}, \quad \text{(Model 3)}$$

where

$$\beta_1^{**} = (\text{DBHIB/DBHOB})_i - \beta_1,$$

and $(\text{DBHIB/DBHOB})_i$ is the ratio for the ith tree.

Freese's (1960) chi-square test for accuracy was employed to determine how well these models predicted the 712 DIB/DOB ratios for the 92 white oak trees. The error limits, expressed as a percentage of the average DIB/DOB ratio, that can be expected to include 95 percent of the deviations between actual and predicted DIB/DOB ratios (5% probability level) are shown in Table 3. The error limits for DIB would be the same as those for the DIB/DOB ratios. As anticipated, the error limits were substantially smaller for Models 2 and 3 than for Model 1, with Model 3 being the smallest.

The mean square errors (MSE) of the differences between actual and predicted DIB/DOB ratios were also calculated for the three models (Table 3). Approximate F-tests for significance were calculated by dividing the larger MSE by the smaller MSE. The MSE for Model 2 was significantly smaller than the MSE for Model 1, and the MSE for Model 3 was significantly smaller than the MSE for Model 2.

Discussion

Trends in the DIB/DOB ratios up the stem for 10 important hardwood species were developed in this study. The coefficients in Table 2 can be used with Model 1 to predict DIBs from DOBs. However, we strongly recommend that a sample of the DBHIB/DBHOB ratios from the stand of interest be used to adjust Model 1 to produce Model 2. If the DBHIB/DBHOB ratio is known for every tree, Model 3 is recommended.

The prediction equations developed in this study should be usable in studies that employ optical dendrometers to measure DOB's up the stem. The equations can also be used in conjunction with taper-based volume equations such as those developed by Martin (1981) for Appalachian hardwoods or those by Hilt (1980) for upland oaks. The taper-based systems integrate over predicted DOB's to predict outside-bark volumes. The equations in this study would be used to convert the predicted DOB's to predicted DIB's. A numerical integration routine would then be used to calculate inside-bark volumes.

Table 3.—Error limits from chi-square tests of accuracy, mean square errors, and F-tests for the three prediction models.

Model	Error[a] limits	MSE	F-test[b]
1	7.9	0.954	3.482**
2	4.3	0.274	1.299**
3	3.7	0.211	

[a]Expressed as a percent of the mean DIB/DOB ratio, 5% probability level.

[b]F = (Larger MSE/smaller MSE), (712,712) degrees of freedom, ** = significant at the α = .01 probability level.

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Hilt, Donald E.; Rast, E. D.; Bailey, H. Predicting diameters inside bark for 10 important hardwood species. Res. Pap. NE-531. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 7 p.

General models for predicting DIB/DOB ratios up the stem, applicable over wide geographic areas, are developed for 10 important hardwood species. Results indicate that the ratios either decrease or remain constant up the stem. Methods for adjusting the general models to local conditions are presented. The prediction models can be used in conjunction with optical dendrometer measurements or stem taper equations to convert outside bark diameters to inside bark diameters.

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Emission Characteristics of Elm Bark Beetle Aggregation Attractants from Controlled-Release Dispensers

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Abstract

Release rates of the aggregation attractants of the smaller European elm bark beetle, *Scolytus multistriatus* (Marsham), from laboratory-aged and field-aged Conrel and Hercon dispensers were monitored for 85 days by GLC analysis of cold-trapped volatiles. Both dispensers had relatively low and constant rates of decay for all three attractant components after an initial burst in emission rates. Within limits, the ratio of components released remained constant over time and at various temperatures.

Introduction

Controlled-release pheromone dispensers, herein called lures, are key elements in the study and effective use of insect attractants. Most identified attractants are a mixture of two or more chemicals. To be most effective, these chemicals must be released in minute, constant amounts at a particular ratio for several days or months and in a variety of environments—not an easy task.

Several companies have developed controlled-release lures. Hercon® laminated plastic dispensers (Health-Chem Corp., New York, NY) and Conrel® hollow-fiber dispensers (Albany International, Needham Heights, MA)[1] are among the most widely accepted for use in insect survey and suppression. The efficacy and longevity of these lures have been evaluated indirectly as part of studies of various insects and their attractants.

In both laboratory and field studies, many changes in controlled-release formulations may be required to optimize release rates or otherwise improve the lures. The use of field tests to evaluate modification in formulation is prohibitively expensive and time consuming, so laboratory evaluations are more practical. Several methods have been used for determining release rates in the laboratory. These include: (1) measurements of weight loss; (2) extraction of residual semiochemicals; (3) direct observation of volume changes in capillary tubes; and (4) trapping of effluent vapors (see reviews by Roelofs 1979 and Weatherston et al. 1981).

Although problems can be encountered in trapping effluent vapors as a method for determining release rates, there are several advantages in using this technique, the most important of which is that it should give the most accurate measurements (Plimmer et al. 1977; Weatherston et al. 1981). Other studies in which this technique has been used for determining release rates have been reported (Beroza et al. 1975; Look 1976; Bierl-Leonhardt et al. 1979; Baker et al. 1980; Cross 1980; Cross et al. 1980). In this paper we describe aeration-vapor trapping and chemical assays of laboratory-aged and field-weathered Conrel and Hercon lures formulated to emit multilure, the three-component aggregation attractant (Pearce et al. 1975) of the smaller European elm bark beetle, *Scolytus multistriatus* (Marsham).

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Materials and Methods

Attractant Collection Technique

The attractants released from lures were collected by an aeration and cold-trapping procedure similar to that described by Gore.[2] Three Hercon and three Conrel lures were placed in six separate glass chambers (approximately 24 cm long by 4 cm (inside diameter)) in a room maintained at 25° ± 1°C. The chambers were flushed with nitrogen for 30 minutes before each collection to expel moisture, air, and any excess pheromone on the lure surface. Each chamber was connected to a glass U-tube immersed in a dry ice-acetone bath. Attractants eluted from the lures were carried by the nitrogen stream (65 ml/minute) to the U-tubes where they were condensed and collected.

After 3 hours of aeration/cold-trapping, each U-tube was disconnected from the aeration chamber and removed from the bath. We immediately pipetted 2 ml of hexane into the U-tube through the glass arm previously attached to the chamber, sealed the tube, and agitated it carefully to dissolve the trapped attractants. No attempt was made to wash the walls of the aeration chamber, where a small amount of the attractants probably had accumulated.

[2]Gore, W. E. 1975. The aggregation pheromone of the European elm bark beetle (*Scolytus multistriatus*): Isolation, identification, synthesis, and biological activity. Ph.D. Thesis. Syracuse, NY: State University of New York; 242 p.

GLC Analysis

The hexane-attractant solution was analyzed by GLC to determine the relative amounts of each attractant trapped. A 3-μl aliquot of each sample solution was injected into a Varian Aerograph Model-1200 gas chromatograph equipped with a flame ionization detector, and a 0.3-cm (outside diameter) by 6.1-m stainless steel column packed with Carbowax 20M on 60/80-mesh Chromasorb G. The helium flow through the column was maintained at 60 ml/minute. Operating temperatures were: injector 185 °C, column 150 °C isothermal, and detector 215 °C. Under these conditions, retention times for the multilure components, 4-methyl-3-heptanol (H), α-multistriatin (M) and α-cubebene (C), were 2.2, 4.2, and 4.7 minutes, respectively.

After each sample was injected and analyzed, a 3-μl aliquot of a standard consisting of known concentrations of the attractants in hexane was injected and analyzed. The amounts of H, M, and C in the standard varied (though the ratios remained constant), depending on the concentration of the three chemicals in the test samples (as indicated by GLC peak heights); that is, a standard with larger concentrations was used to compare with unaged lures, while a standard with lower concentrations of H, M, and C was used to compare with baits that had been aged for some time in the laboratory or field. The peak heights of the samples were compared with peak heights of the standards to calculate the approximate relative concentration of each attractant component in the sample. We calculated release rates in terms of μg/day by multiplying concentration by amount of solvent by aeration time.

Standard solutions were assayed at various aeration gas flow rates, aeration periods and temperatures to determine a set of operating parameters that yielded a high and consistent recovery rate.

Verification of Technique

To verify the precision and accuracy of this aeration-collection-assay technique, five standard solutions containing known amounts of H, M, and C in hexane were pipetted onto filter paper and placed in separate aeration chambers. Volatiles were collected for 4 hours, after which time analysis by GLC was performed. The five standard solutions contained the following dose equivalents (μg/day H:M:C): 1440:360:2880, 720:180:1440, 288:72:576, 144:36:288, 72:18:144 (Table 1). Because the actual aeration time was only 4 hours, the amount of each chemical applied to the filter paper was actually one-sixth of the quantities listed.

Test Conditions

The release rates of lures were measured under two test conditions: (1) from carefully selected lures aged under uniform controlled laboratory conditions; and (2) from randomly selected lures aged in the field. For the first test we carefully selected lures from the general lot on the basis of apparent physical homogeneity; i.e., uniformly filled tubes in Conrel lures and uniform size and shape in Hercon lures. The lures, three each of Conrel and Hercon, were placed in aeration chambers (identical to those used to collect samples for determining release rates) at 25° ± 1 °C and 65 ml/minute air flow (from laboratory compressed air system) for 85 days. Lures were removed from this system at various intervals during this time and subjected to the aeration-collection-assay technique described.

Lures for the second test, three of each type, were indiscriminately selected from the general lot. They were stapled to a protective cover, attached to a sticky trap, and placed on utility poles (these are the same procedures used in survey or suppression studies) (Lanier 1978, 1979; Lanier et al. 1976; Peacock 1981, 1982) for 85 days. At various intervals, the lures were brought into the laboratory, assayed, and returned to the field.

Results and Discussion

Verification of Assay Technique

Under the conditions of these tests, the release of attractant from lures ranged from about 20:10:100 μg/day of H:M:C to about 2000:500:2500 μg/day. The precision and accuracy of the aeration-collection-assay technique in measuring known amounts of attractants applied to filter paper were fairly constant over this range (Table 1). The standard errors were less than 3 percent of the mean. The percent recovery, which measures efficiency of the system, was about 89 for H, 83 for M, and 75 for C. Although it is clear that the technique consistently underestimated the relative amounts of all three components, it was sufficient to differentiate between lures and to monitor changes in relative release rates over time.

Table 1.—Precision and accuracy of the aeration-collection-GLC technique as indicated by percent recovery after aeration-collection of known amounts of three multilure components

Dose of H:M:C aerated[a]	Dose recovered (μg/day ± SE)			Percent recovery		
	H	M	C	H	M	C
1440:360:2880	1284 ± 12	312 ± 9	2066 ± 31	89	87	72
720:180:1440	641 ± 12	150 ± 6	1106 ± 17	89	83	77
288:72:576	251 ± 5	57 ± 2	445 ± 6	87	79	77
144:36:288	132 ± 1	30 ± 1	213 ± 1	92	83	74
72:18:144	63 ± 1	14 ± 1	112 ± 3	88	78	78

[a]Dose aerated refers to equivalent amounts of each component in μg/day initially applied on filter paper in aeration chamber. H:M:C represents 4-methyl-3-heptanol: α-multistriatin: α-cubebene, the components of multilure.

Effects of Temperature

A temperature increase of 10 °C generally more than doubled the release rates of all components from both types of lures in lab tests (Fig. 1). Hercon lures (Fig. 1A) were somewhat more temperature sensitive (steeper slopes) than Conrel lures (Fig. 1B) over the range tested. Temperature did not appreciably affect the ratio of components released even though the components have different volatilities. Along with the difference between types of lures, this suggests that temperature sensitivity depends more on the design of the lures than on the characteristics of the chemicals released. Since the ratio of components was not radically affected by temperature, these temperature-induced changes may be advantageous; that is, attractants are conserved during cool periods when beetles are inactive, but are released in large doses when temperatures are high and beetles are responsive.

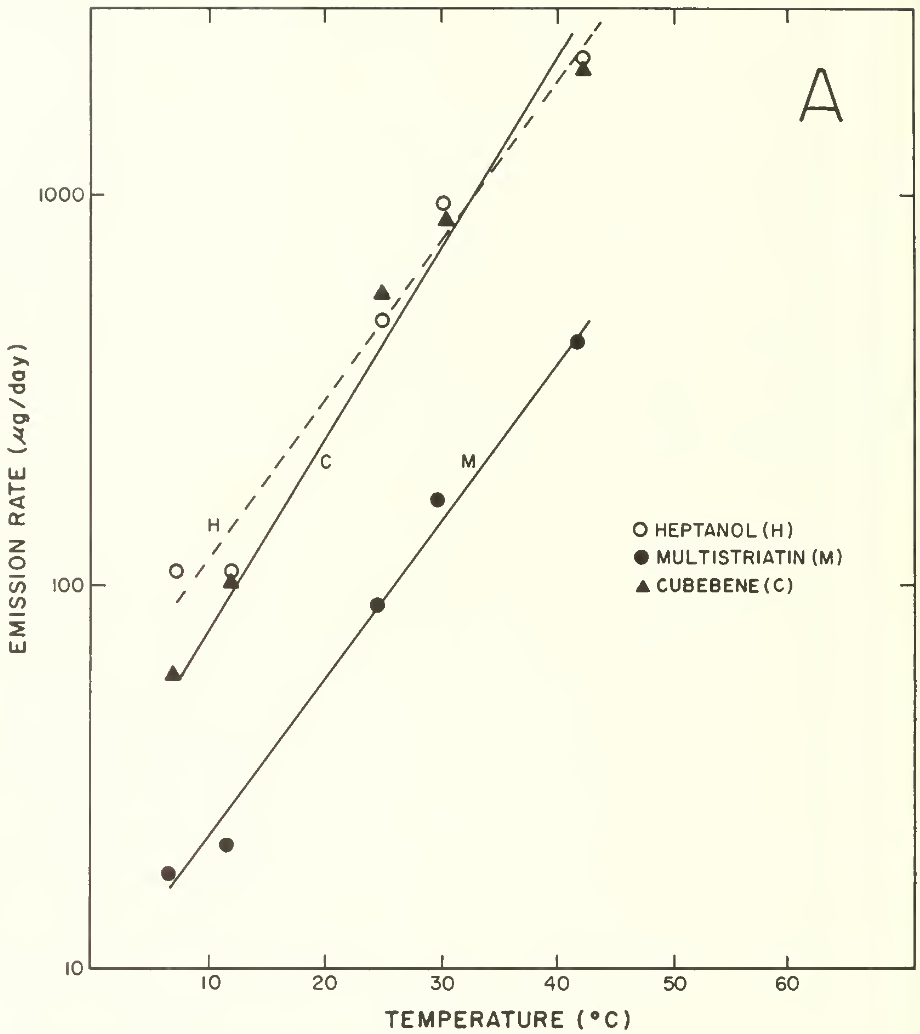
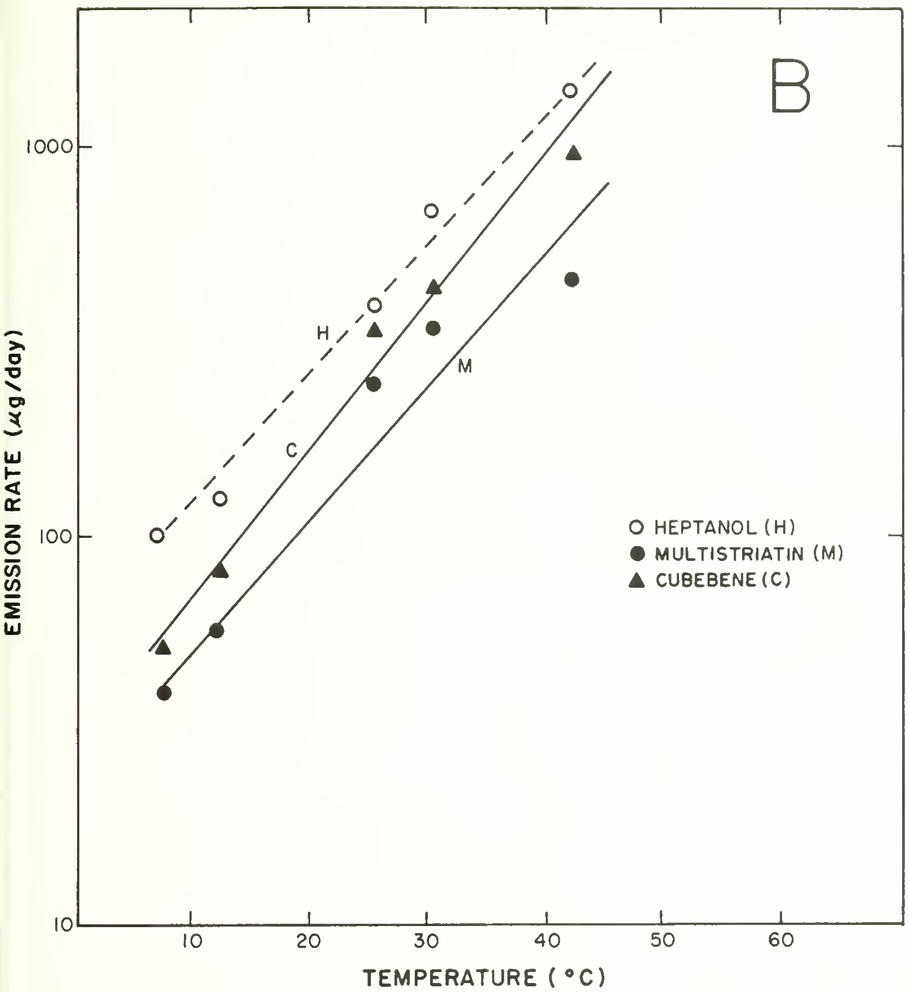


Figure 1.—Effects of temperature on mean release rates of multilure components from controlled release attractant dispensers: (A) Hercon lures; (B) Conrel lures (based on two lures of each type).


B
EMISSION RATE (μg/day)
1000
100
10
10
20
30
40
50
60
TEMPERATURE (°C)
H
C
M
HEPTANOL (H)
MULTISTRIATIN (M)
CUBEBENE (C)

Initial Release Rates

For at least a week after initial exposure of the lures (about 7 days for Hercon, 11 days for Conrel) release rates of all components greatly exceeded the specified rates (the lures were designed to release 400:100:800 μg/day of H:M:C) (Table 2). But the release rates fell sharply during those periods. By the 11th day, the emission rate from Conrel lures was about half the initial rate, and the emission rate from Hercon lures, which initially was higher than that from the Conrel lures, declined even more. The release rates of all components from both lures were near or well below the specified rates after 11 days. However, the high initial rates obviously resulted in a significant percentage of the total pheromone in the baits being emitted during the first 2 weeks of exposure —about one-fourth of the original 49 mg of H in Hercon lures was emitted during that period. In the practical use of lures, these high and rapidly changing rates could introduce bias and variability into measurements of beetle response, especially in short-term tests of beetle behavior. We expected some initial burst in emission rates due to the accumulation of pheromone on the surface of the lures while they were packaged, but not at the magnitude or duration recorded in this test. Because these initial rates were not typical of the longer-term rates, we deleted the data for the first 2 weeks in evaluating and comparing long-term release rates for the three compounds.

Table 2.—Initial release rates (0-11 days) of multilure components from laboratory-aged Hercon and Conrel lures

Lure and component	Mean[a] release rate (μg/day ± SE) after exposure for—			
	0 days	3 days	7 days	11 days
Hercon				
Heptanol	2193 ± 202	683 ± 54	445 ± 31	267 ± 14
Multistriatin	327 ± 21	123 ± 9	85 ± 8	50 ± 3
Cubebene	1121 ± 16	833 ± 15	763 ± 84	514 ± 45
Conrel				
Heptanol	1356 ± 39	986 ± 95	744 ± 70	532 ± 76
Multistriatin	246 ± 16	219 ± 25	196 ± 14	140 ± 16
Cubebene	862 ± 91	933 ± 69	751 ± 217	469 ± 58

[a]Mean values for three of each type of lure.

Release Rates from Laboratory- and Field-Aged Hercon and Conrel Lures

The data from release rate determinations are shown in Figure 2. They indicate a daily emission rate of 1 to 3 percent of the amount of attractants remaining from the previous day. There are some large differences in these curves (between Hercon and Conrel, field- and laboratory-aged); these resulted from a combination of factors including the selection process, weathering-aging conditions, and differences in lures.

Some of the differences in release rate curves between laboratory- and field-aged lures were due to the selection process. As might be expected, the release rates from randomly selected (field-aged) lures were more variable than visually selected (laboratory-aged) lures (Table 3). The selection process also resulted in differences in the dose detected. Careful selection of Conrel lures, in which the attractants are visible, allowed us to choose lures with higher average release rates than those that were randomly selected from the general lot. But we were unable to select for high release rates from Hercon lures, in which the attractants are impregnated in opaque, laminated plastic. In fact, the average rates of H and M from randomly selected Hercon lures were higher than from carefully selected lures (Table 3).

Table 3.—Mean release rates[a] and release-rate ratios for three components of multilure from laboratory- and field-aged Hercon and Conrel lures on given days

Lure and component	Day 14 (μg/day ± SE)	Ratio	Day 44 (μg/day ± SE)	Ratio
Lab-aged Hercon				
Heptanol	232 ± 21[b]		66 ± 7	
Multistriatin	45 ± 6	5.2:1:9.3	16 ± 9	4.1:1:14
Cubebene	482 ± 52		219 ± 8	
Field-aged Hercon				
Heptanol	416 ± 53		107 ± 14[c]	
Multistriatin	73 ± 10	5.7:1:5.8	28 ± 4	3.8:1:6.5
Cubebene	426 ± 28		183 ± 7	
Lab-aged Conrel				
Heptanol	669 ± 145[b]		243 ± 18	
Multistriatin	206 ± 27	3.2:1:2.3	91 ± 18	2.7:1:1.5
Cubebene	471 ± 18		135 ± 3	
Field-aged Conrel				
Heptanol	274 ± 35		132 ± 16[c]	
Multistriatin	126 ± 21	2.2:1:2.9	39 ± 6	3.4:1:1.7
Cubebene	369 ± 77		68 ± 11	

[a]Mean values for three of each type of lure.
[b]Release rates at day 15.
[c]Release rates at day 42.

The smaller slopes of the field-weathered lures indicate that these lures were depleted more slowly than those aged in the laboratory (Fig. 2), probably for the most part because the average temperature in the field was lower than in the laboratory. However, the air flow around lures, moisture content in the air, and solar radiation may also have influenced depletion rate.

Despite problems introduced by the selection and aging processes, some differences between types of lures are apparent. The slopes of H and M from Conrel lures, whether laboratory-aged or field-aged, were lower than those for Hercon (Fig. 2A, B). This means the average output of these components from the Conrel lures was more constant. The situation was reversed for C because Hercon lures had a more constant C output (lower slope) (Fig. 2C). These differences in slopes are reflected in the average release rates at 44 days, which is approximately the specified half-life of the lures and a period generally coincident with peak beetle abundance in suppression tests (Lanier et al. 1976). At 44 days, Conrel lures released H and M at higher rates (Fig. 2A, B) than Hercon and C at lower rates (Fig. 2C).

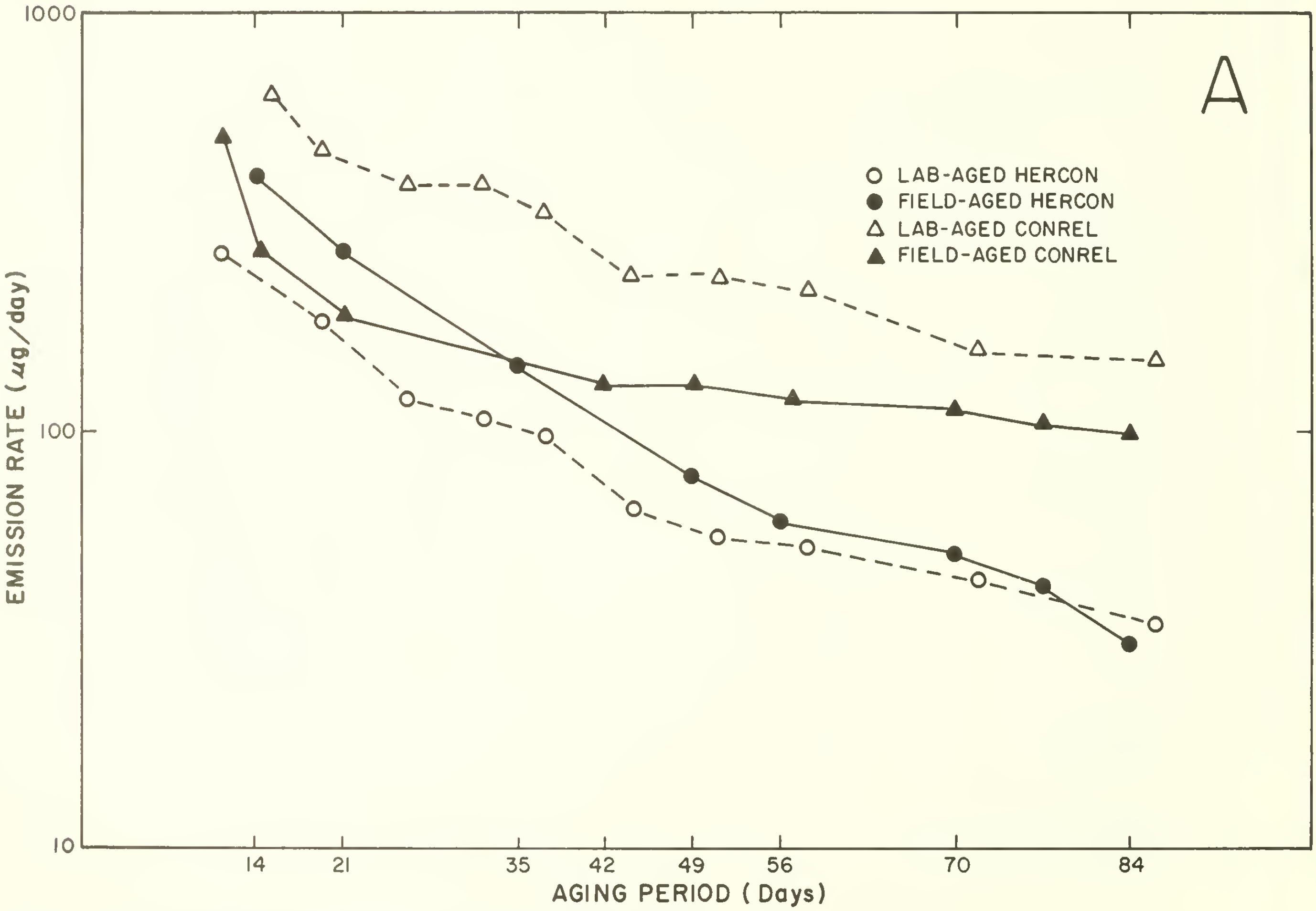
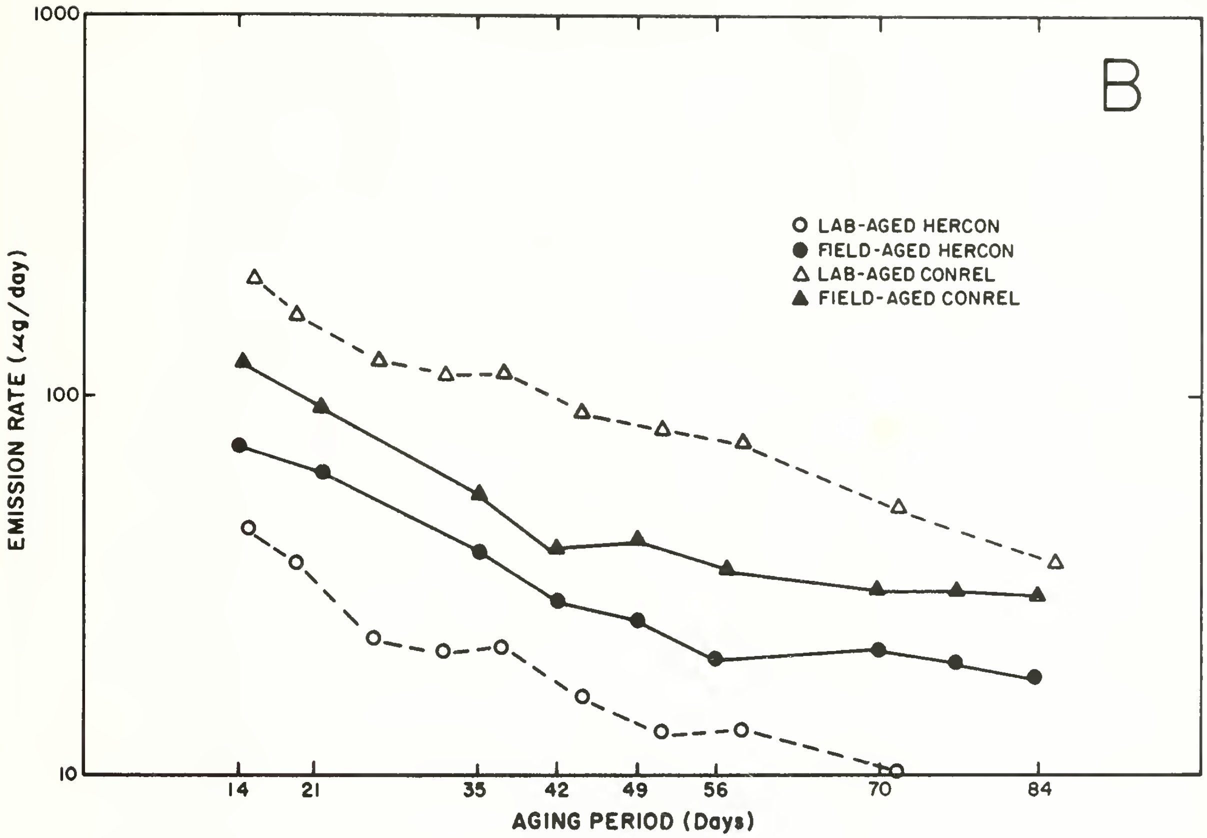
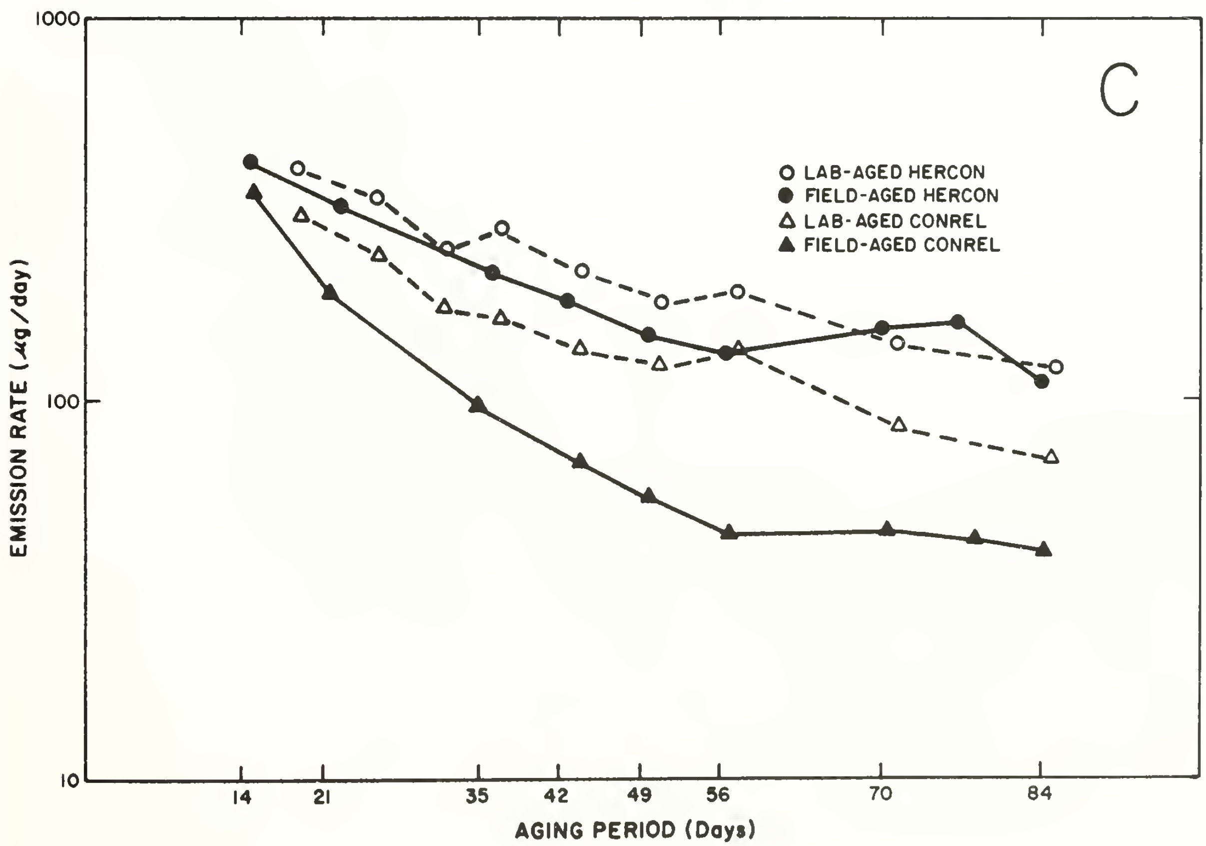


Figure 2.—Mean release rates of multilure components from laboratory- and field-aged Hercon and Conrel lures: (A) for 4-methyl-3-heptanol; (B) for α-multistriatin; (C) for α-cubebene (three lures of each type).


B
LAB-AGED HERCON
FIELD-AGED HERCON
LAB-AGED CONREL
FIELD-AGED CONREL
EMISSION RATE (µg/day)
1000
100
10
14
21
35
42
49
56
70
84
AGING PERIOD (Days)


C
LAB-AGED HERCON
FIELD-AGED HERCON
LAB-AGED CONREL
FIELD-AGED CONREL
EMISSION RATE (µg/day)
1000
100
10
14
21
35
42
49
56
70
84
AGING PERIOD (Days)

The lures differed not only in relative release rates of the three components but at 44 days (except for laboratory-aged Conrel for H and M), both lures also released doses well below those specified (400:100:800 μg/day H:M:C). We expected this decrease but consider it only moderately important for two reasons. First, the average dose released from either lure can be manipulated easily by changing the size (Hercon) or number of fibers (Conrel). In fact, the specified rates were higher than needed for maximum beetle catch; we have deliberately specified high rates to ensure an adequate rate throughout the trapping period (90 days). Second, above a certain threshold the absolute dose emitted is much less important in attracting beetles than the ratio of components. Attractiveness of the pheromone blend depends heavily on the ratio in which components are emitted—especially the ratio of H to M (Lanier et al. 1977; Cuthbert and Peacock 1978). The lures differed significantly in this respect (Fig. 2, Table 3).

The average ratio in which H to M was emitted from field-aged Conrel increased slightly over time. Although the release rate ratio of H to M for Conrel lures was more stable than that for Hercon lures, the ratio from Hercon lures was closer to that specified at the time of manufacture (400:100:800). For example, the average ratio for field-aged Conrel lures was about 2.2 to 1 ($\frac{274}{126}$) at day 14 and 3.4 to 1 ($\frac{132}{39}$) after 44 days exposure. The average ratio for field-aged Hercon lures was about 5.7 to 1 at 14 days and 3.8 to 1 at day 44 under the same conditions (Table 3). Even though Conrel lures generally had a higher, more stable release rate than Hercon, the ratio of H to M was closer to specifications for Hercon lures—and the Hercon lures caught 50 percent more beetles in concurrent suppression tests.[3]

However, some lures of either type are likely to have a low, suboptimal ratio of H to M (less than 2 to 1). Although the data show the average ratios usually were greater than 3 to 1, the standard errors indicate that some lures in the general lot would be expected to have much lower, less attractive ratios. Using actual data as an example, the average release rates from field-aged Conrel lures at 14 days indicate a 2.2 to 1 ratio of H to M (Table 3). But in some lures the output of H could be less than 240 (274 − 35), and the output of M could exceed 147 (126 + 21), which would result in a suboptimal ratio (1.6 to 1). The proportion of suboptimal lures cannot be estimated accurately from these data because the release rates of H and M for a given lure are not necessarily independent.

[3]The Conrel lures were redesigned to reduce the output of α-multistriatin. As a result, the attractiveness of Conrel lures equaled that of Hercon lures (Peacock, J. W., unpublished).

Conclusions

On the basis of these tests, we have no strong reason to assume that either the Hercon or Conrel lure is better than the other. Although both lures differed significantly in many particulars (dose, ratio, initial rates), overall release-rate characteristics were similar. After an initial burst, both types had relatively constant release rates, depleting at a rate of about 1 to 3 percent per day. The release rates from both types of lures only approximated the specified doses and ratios, but these can be (and were) easily adjusted in subsequent formulations. Most important, the ratio of components released from the lures was relatively constant over the life of the lures and at different temperatures. The measured variation among lures of the same type indicated that most lures emit an acceptable ratio of H to M, but also that some proportion of both lures emits a suboptimal ratio. Both lures were highly temperature-sensitive. And since field temperatures commonly differ by several degrees between locations and even from hour to hour, the differences in release rates due to temperature probably are larger than those due to daily degradation of lures or to the differences between and among the lures.

Acknowledgments

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Cuthbert, R. A.; Peacock, J. W.; Wright, S. L. **Emission characteristics of elm bark beetle aggregation attractants from controlled-release dispensers.** Res. Pap. NE-532. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 11 p.

Release rates of the three-component aggregation attractant of the smaller European elm bark beetle, *Scolytus multistriatus* (Marsham), from laboratory-aged and field-aged Conrel and Hercon dispensers were monitored for 85 days by GLC analysis of cold-trapped volatiles. Both dispensers had relatively low and constant rates of decay for all three attractant components after an initial burst in emission rates. Within limits, the ratio of components released remained constant over time and at various temperatures.

ODC 414.11—145.7 × 19.92

Keywords: *Scolytus multistriatus;* pheromone; *Ulmus;* lures; volatiles

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Individual-Tree Diameter Growth Model for Managed, Even-Aged, Upland Oak Stands

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Abstract

A distance-independent, individual-tree diameter growth model was developed for managed, even-aged, upland oak stands. The 5-year basal-area growth of individual trees is first modeled as a function of dbh squared for given stands. Parameters from these models are then modeled as a function of mean stand diameter, percent stocking of the stand, and site index. A stochastic option for the overall model also was developed. Tests on data from managed stands revealed that the model performed well.

Introduction

Forest managers in the upland oak timber type need reliable growth and yield information to intelligently evaluate alternative management practices. The information presented in this paper is related to one of the most important aspects of managing even-aged upland oak stands—intermediate thinnings. Growth and yield prediction equations developed by Dale (1972) have provided the best information to date for projecting future yields of thinned oak stands. However, these prediction equations are classified as stand growth models, as opposed to individual-tree growth models (Munro 1974). Stand models often do not provide sufficient resolution of the yield predictions to solve many of the problems facing the forest-land manager. Individual-tree growth models predict growth rates for individual trees. These are summed to obtain stand estimates. Since the growth rates are estimated for each tree, important information regarding the *species* and *size class* of trees in the projected stand is available. This information is critical for determining the value of trees in the projected stand, an essential ingredient for evaluating the economic aspects of thinning hardwood stands.

This study is one of a coordinated series of studies designed to develop an individual-tree growth simulator for upland oak stands. Mathematical models that predict the diameter growth rates of individual trees were developed in this study. Earlier studies have developed models for estimating future tree heights (Hilt and Dale 1982) and computing various tree-volume estimates (Hilt 1980). Future studies will be aimed at constructing mortality and ingrowth models. These components models will be combined into a working individual-tree growth simulator. Managers will be able to use the simulator to predict future yields for alternative types, intensities, and frequencies of intermediate thinnings. The growth and yield information generated by the simulator for each alternative thinning regime, coupled with economic evaluation, will help the manager make the most appropriate decision regarding thinning.

The individual-tree diameter growth model developed in this study can be classified as distance-independent (Munro 1974), and can be applied to a wide range of age, site, and stocking conditions for even-aged upland oak stands. Individual-tree growth models developed by Dale (1975) for upland oak stands apply only to 80-year-old white oak stands. Three interrelated growth models are developed in this study: (1) mean model; (2) random model; and (3) random/known model. The mean model refers to the basic individual-tree diameter growth model. The random model is a modification that uses the mean model as the underlying growth model, and the random/known model is identical to the random model but assumes some knowledge of past growth.

Data

Data used in this study were collected on seventy-seven 0.25- to 1.0-acre permanent growth and yield plots located in southern Ohio and southeastern Kentucky. The plots were established in 1962 over a wide range of age and site conditions in areas representative of fully stocked even-aged upland oak stands that showed little evidence of recent fire or logging. Plot ages, determined from increment borings and ring counts on stumps after thinning, ranged from 29 to 93 years. Site index, the height attained by the average dominant and codominant oak at total age 50, was determined from Schnur's (1937) site index curves for upland oaks and ranged from 60 to 77.

Species composition ranged from nearly pure white oak on some Kentucky plots to a mixture of black and scarlet oaks on some Ohio plots. Hickory constituted a minor component of the overstory on some plots. Other species in the understory included yellow poplar, red maple, serviceberry, sourwood, and dogwood.

Most plots were thinned in 1962 to specified basal area levels or specified stocking levels according to Gingrich's (1967) tree-area-ratio equation (Figs. 1-3). Three plots were not thinned. Percent stocking ranged from 16 to 94 after the initial thinnings. The thinning method used is best described as "free thinning" —the marker was free to remove trees from all crown classes. The objective was to leave the specified stocking level distributed on the best trees as evenly spaced as possible throughout the plot. An isolation strip around each plot also was thinned. Twenty-seven plots received a second thinning after 10 growing seasons.

Figure 1.—White oak plot in Kentucky, age 33. Stocking was reduced to 37 percent.

Figure 2.—Mixed oak plot in Ohio, age 32. Stocking was reduced to 48 percent.

Figure 3.—White oak plot in Kentucky, age 77. Stocking was reduced to 58 percent.

Every tree larger than 2.5 inches dbh was numbered and its species identified in 1962. Successive dbh measurements were recorded in 1962, 1967, 1972, and 1977. Growth statistics for the three 5-year periods were derived from these measurements. Only those trees larger than 2.5 inches dbh in 1962 were analyzed. Ingrowth was excluded from the analysis because it is just now beginning to influence the growth of trees in the overstory. All trees used in the analysis were appropriately summed to obtain plot characteristics such as percent stocking, mean stand diameter, and basal area per acre. However, growth-model parameters were fitted only to those trees of the five major commercial oak species: white, black, scarlet, chestnut, and northern red. These five species constituted 84 percent of the 9,455 trees larger than 2.5 inches dbh after thinning in 1962.

Methods and Results

Model Development

The individual-tree diameter growth model was developed within limitations imposed by the data. A distance-independent model was developed because stem maps were not available for most plots. Stem maps prepared at the present time would not be useful because many trees have died or have been subsequently thinned since the initial measurements. Dbh was the only variable recorded for each tree. Other variables such as crown ratio or crown class might have been useful for explaining variations in tree growth, but were not measured. Individual-tree growth, therefore, was modeled as a function of tree dbh and stand (plot) attributes. A major advantage of the resulting distance-independent model over distance-dependent models is that it allows for faster computing during execution, permitting rapid testing of many alternative management hypotheses (Munro 1974).

The underlying assumption for using the diameter growth model developed in this study is that the user has access to a tree list for the stand. A tree list usually can be obtained by sampling the specific stand of interest. Species and dbh should be recorded for each tree sampled.

The basic growth model proposed for development has the form:

$$BAG5YR_{ij} = f(DBH_{ij}, SI_i, \overline{D}_i, PS_i) \quad (1)$$

where

$BAG5YR_{ij}$ = 5-year basal-area growth (ft^2) for the jth tree in the ith stand,
DBH_{ij} = DBH (inches) of the jth tree in the ith stand,
SI_i = site index of the ith stand,
$\overline{D}_i$ = mean stand diameter (quadratic mean) of the ith stand, computed from trees larger than 2.5 inches dbh in the original tree list,
PS_i = percent stocking of the ith stand, summed over trees larger than 2.5 inches dbh in the original tree list with Gingrich's (1967) stocking equation: $PS_{ij} = -.005066 + .016977\ DBH_{ij} + .003168\ (DBH_{ij})^2$

I used basal-area growth as the dependent variable rather than diameter growth because visual relationships between variables are easier to detect when observing scatter plots of the data if basal-area rates are used. West (1980) found that the correlation between basal-area increment and initial diameter was greater than that between diameter increment and initial diameter. However, the precision of estimates of future diameters were the same whether basal-area or diameter-increment equations were used.

The independent variables included in the model were limited to those previously found to have a significant effect on tree diameter growth for oaks (Dale 1975). Much of the variation in tree growth can be explained with initial tree size (DBH). The other variables reflect those stand attributes that most affect tree growth: site index reflects site productivity, mean stand diameter reflects the size of the trees in the stand, and percent stocking reflects the degree of "crowding" in the stand. Stand age could be used in place of mean stand diameter, but it is determined with less reliability than mean stand diameter, which is calculated from the tree list. DBH and percent stocking also are obtained from the tree list. Site index can be readily determined in the field.

It is important to realize that other models may have performed as well as the hypothesized model. For example, another excellent combination of independent variables would be dbh, number of stems per acre, and basal area per acre. However, since the proposed model performed well, no other models were explored because of the time and costs involved with model development.

Mean Model

A two-stage model building procedure was used to develop the mean growth model. BAG5YR was first modeled as a function of DBH for each stand (plot). The parameters from these models were then modeled as a function of SI, $\overline{D}$, and PS.

First-stage.—Investigation of scatter plots of BAG5YR on DBH (Fig. 4) suggests the development of the following first-stage model for each stand:

$$BAG5YR_{ij} = \beta_{1i}(DBH_{ij}) + \beta_{2i}(DBH_{ij})^2 + \beta_{3i}(DBH_{ij})^3 \quad (2)$$

where β_{1i}, β_{2i}, β_{3i} are parameters to be estimated for the ith stand. The equation is forced through the origin to prevent negative growth predictions. Given this condition, stepwise regression procedures revealed that the $(DBH_{ij})^2$ term was the most significant variable for 75 percent of the plots. The added effect of the other two terms usually was not significant. The first-stage model, therefore, was simplified to the following form:

$$BAG5YR_{ij} = \hat{\beta}_i \cdot (DBH_{ij})^2 \quad (3)$$

where $\hat{\beta}_i$ is the sample estimate of the true parameter, β_i, in the ith stand. In other words, BAG5YR has a quadratic trend over DBH, i.e., the 5-year basal-area growth of a tree is linearly related to the initial basal area of the tree. Ordinary least-squares analyses were performed to obtain unbiased estimates of the β's. Some plots displayed heterogeneous variance about the regression line, which indicated that weighted regression techniques would be required to obtain minimum-variance estimates of the β's. However, ordinary least-squares estimates were considered satisfactory for the first stage of the modeling procedure because of the difficulty in determining proper weights for each plot. The calculated r^2 for equation (3) on most plots was about 0.70.[1]

[1]Calculated $r^2 = 1 - \Sigma(y_i - \hat{y}_i)^2/\Sigma(y_i - \bar{y})^2$

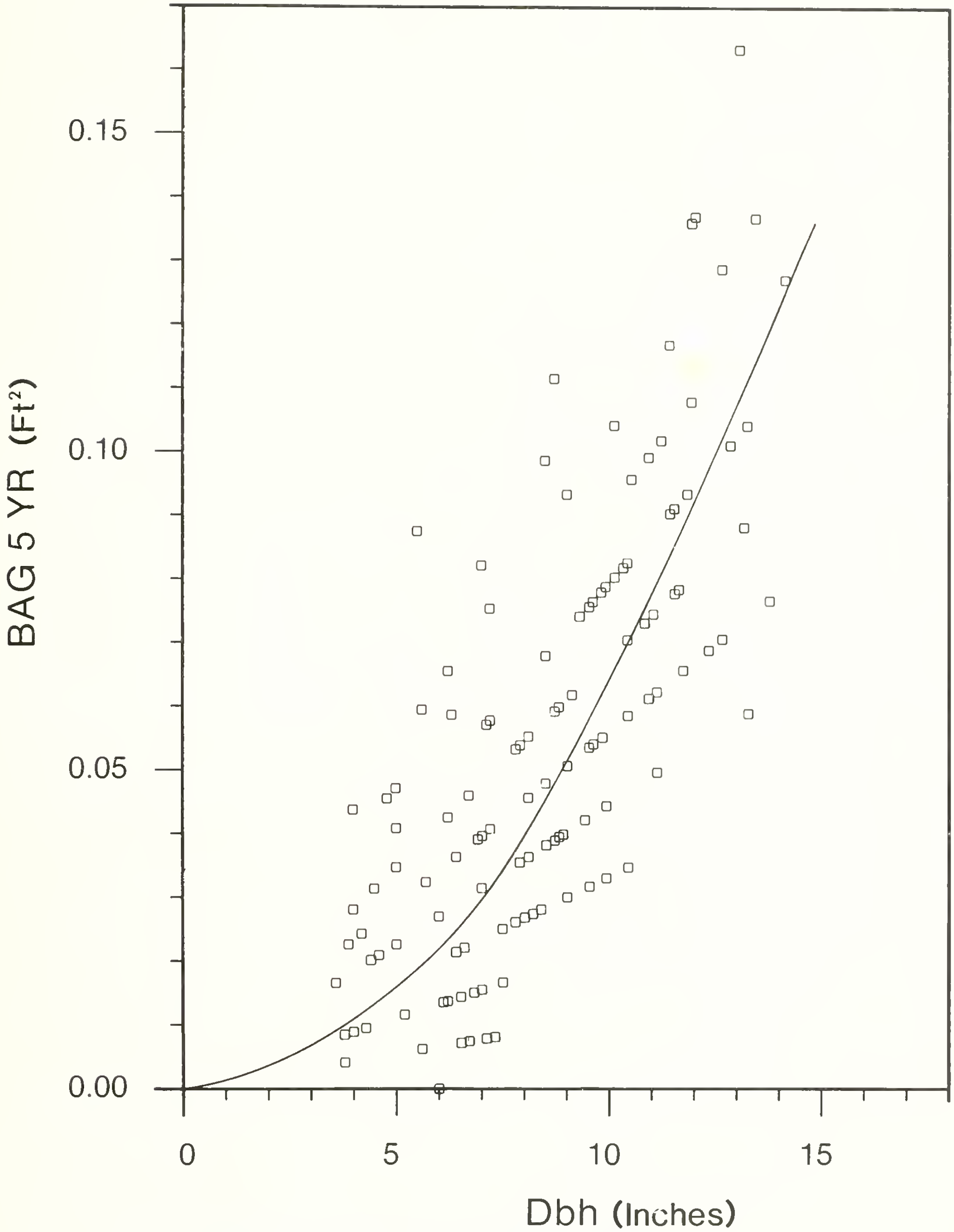

Figure 4.—Scatter plot illustrates quadratic trend in BAG5YR over DBH for 77-year-old white oak stand (BAG5YR = 0.00065804 DBH², calculated $r^2 = 0.58$).

Since the data set contained few trees larger than 18 inches dbh, I was somewhat hesitant about accepting equation (3) as the first-stage model because the predicted 5-year basal-area growth can be very large for big trees due to the quadratic nature of the equation. One approach would be to limit model applications to the range of the data. However, growth predictions may be necessary in stands that contain very large trees. Therefore, an independent sample of individual tree growth rates for large trees was made in stands in southern Ohio. Several older, even-aged, mixed oak stands that contained many trees larger than 20 inches were sampled. Increment borings were used to determine past growth rates. Scatter plots of the past growth rates revealed no reason to reject equation (3) for very large trees (Fig. 5).

Scatter plots of all data revealed that equation (3) does not need to be adjusted for different oak species (Fig. 6). Tree size (DBH) accounts for most of the species effect on tree growth. In other words, big trees grow faster—regardless of species. Trees in the black oak group (black, scarlet, and northern red) usually are larger, hence faster growers, than white and chestnut oaks in a given stand (see stand tables in Schnur 1937, and Figure 6). Since this differentiation in tree size between species begins at an early age, growth models for very young stands would have to allow for different growth rates for different species. The growth models developed in this study should be applied only to stands where the size differentiation has already occurred—stands at least 30 years old.

A total of 231 $\hat{\beta}$'s were fitted—one for each of the three 5-year growth periods for the 77 plots. Correlations between growth rates for the three growth periods on a given plot were not considered during the construction of the mean model. They were, however, considered during development of the random model. The next step in developing the mean model was to model the $\hat{\beta}$'s as a function of SI, $\overline{D}$, and PS.

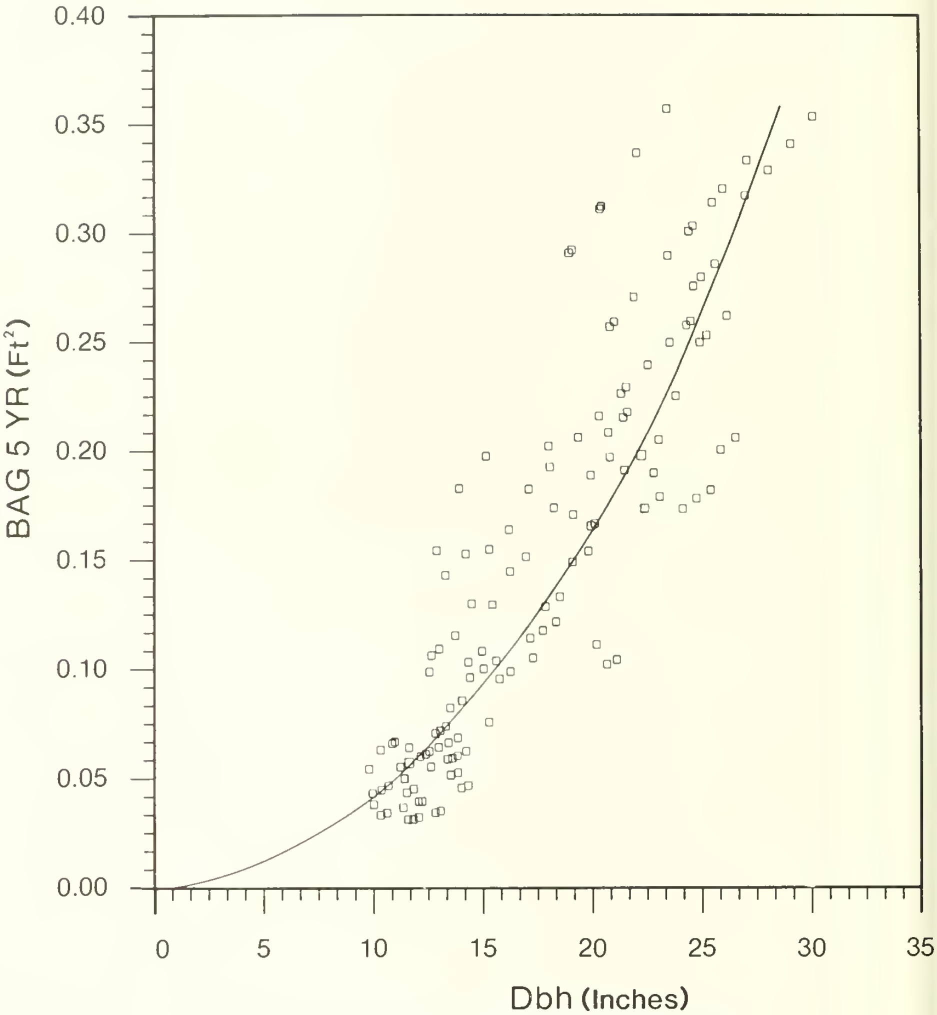

Figure 5.—Scatter plot illustrates quadratic trend in BAG5YR over DBH for 110-year-old stand, site index 75, that contained many large trees (BAG5YR = 0.00043849 DBH², calculated r² = 0.77).

Second-stage.—The value of $\hat{\beta}$ is indicative of the basal-area growth for a given size tree. Scatter plots of the 231 $\hat{\beta}$'s revealed, as expected, that $\hat{\beta}$ increases as percent stocking is decreased. However, this increase is not as large for stands with larger mean stand diameters. The scatter plots also indicated that $\hat{\beta}$ increased on better sites.

The $\hat{\beta}$'s were best estimated with the following nonlinear equation:

$$\hat{\beta}_i = \hat{\gamma}_1 SI_i^{\hat{\gamma}_2} \cdot EXP(\hat{\gamma}_3 \overline{D}_i + \hat{\gamma}_4 PS_i) \qquad (4)$$

where $\hat{\gamma}_1$-$\hat{\gamma}_4$ are sample estimates of the true parameters, γ_1-γ_4, and EXP is the base of the natural logarithms. After logarithmic transformation, model parameters were estimated with a general linear model computer program:

$$\hat{\beta}_i = (6.96762087 \times 10^{-6}) SI_i^{1.5731724} \cdot$$

$$EXP(-.11839854\overline{D}_i - .01198244PS_i) \qquad (5$$

The calculated r² value was 0.76. Predicted $\hat{\beta}$'s for site index 70 are shown in Figure 7.

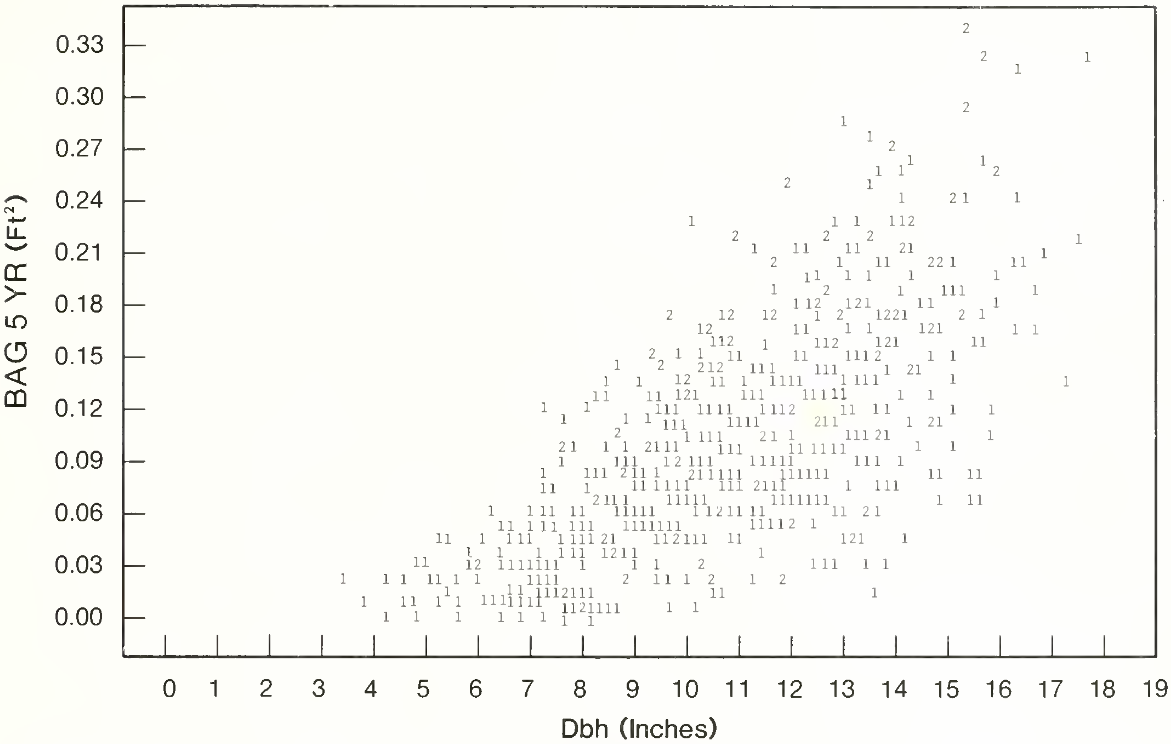

Figure 6.—Scatter plot of BAG5YR over DBH for all trees in the following category: SI < 65, 10 < $\bar{D}$ < 15, and 40 < PS < 60. White oak and chestnut oak = 1; black, scarlet, and northern red = 2. Many code 1's were plotted first; note how code 2 overlaps code 1.

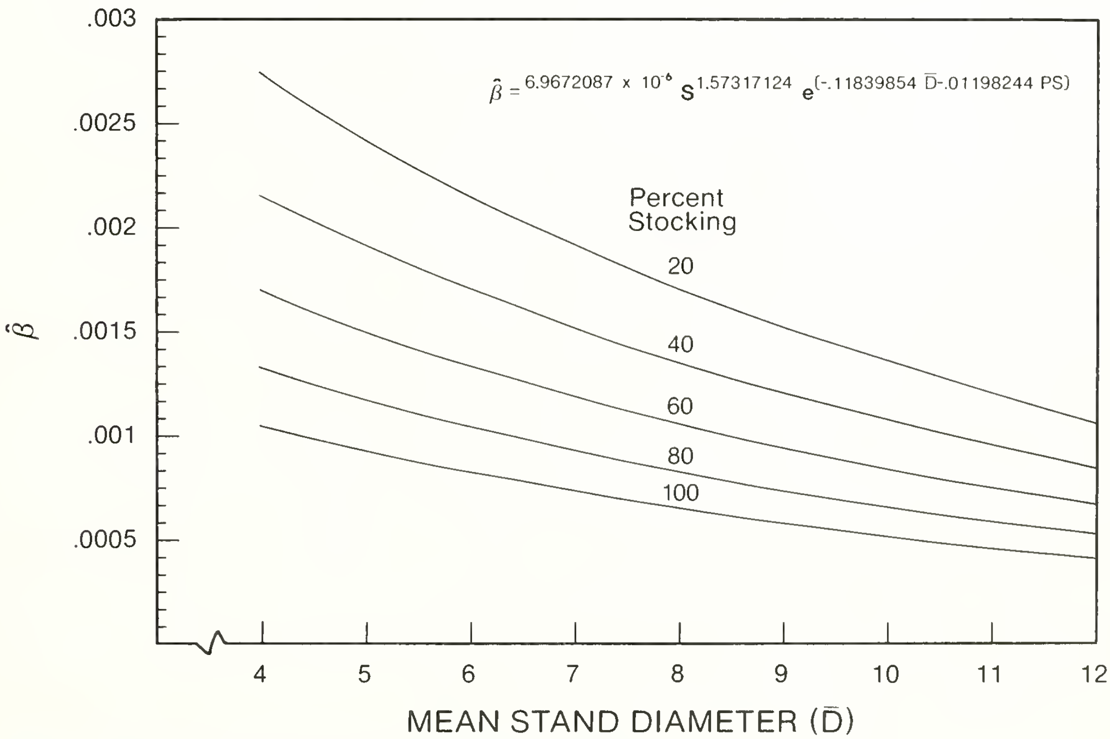

Figure 7.—Predicted $\hat{\beta}$'s for the equation BAG5YR = $\hat{\beta}$ (DBH)^2, site index 70.

Random Model

Predicted growth rates and residuals (actual BAG5YR-predicted BAG5YR) for all trees were calculated using equation (5) to determine $\hat{\beta}_i$ in equation (3). The overall calculated r^2 value was 0.66. Predicted growth rates for a range of stocking and mean stand diameter conditions are shown in Figure 8 for site index 70.

The mean model, as discussed later, predicts individual-tree growth very well on the average. However, the quadratic nature of equation (3) does not allow trees within a given stand to change positions. Big trees always will be grown faster than smaller trees. Even though this feature of the mean model may not be serious regarding overall growth predictions, it is not realistic because trees do change positions. Methodology developed by Dale (1975) expands on the mean model by the use of a random growth component and a bivariate normal distribution between successive growth periods to allow trees to change positions.

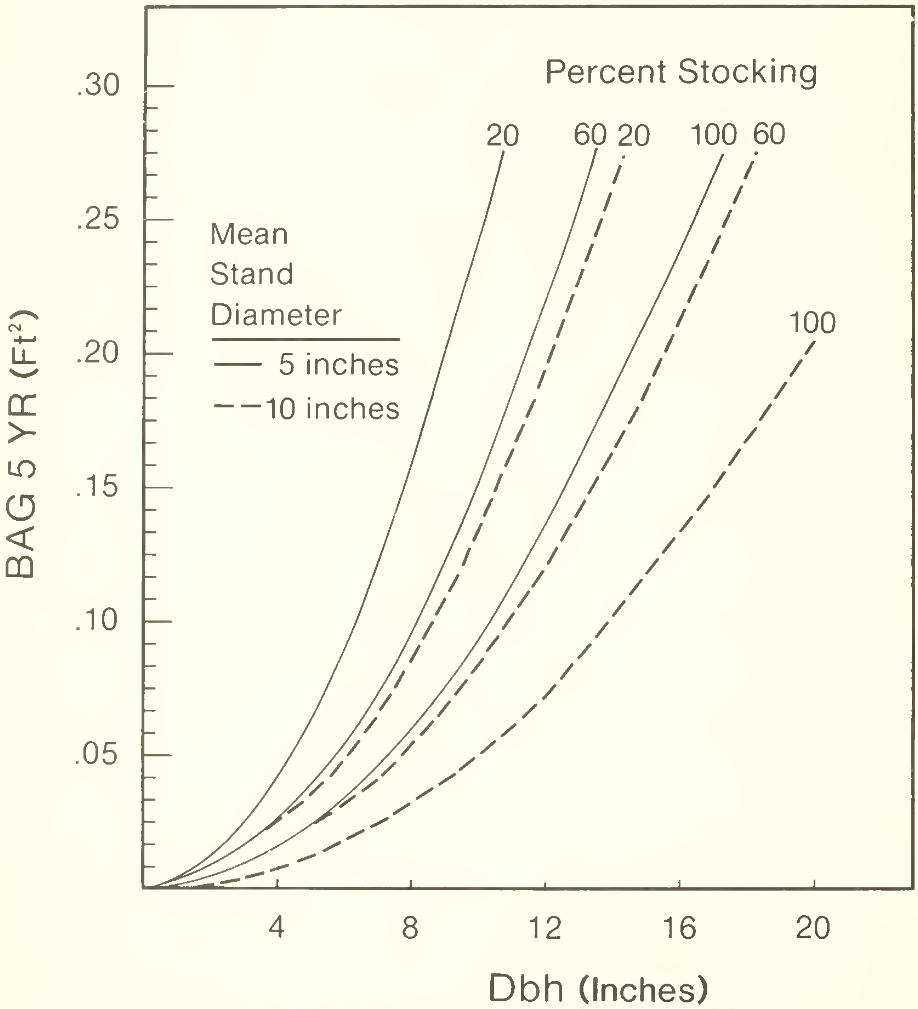

Figure 8.—Predicted 5-year basal-area growth rates (BAG5YR) for site index 70.

Data plotted in this study supported Dale's initial conclusion: (1) BAG5YR was distributed symmetrically within most given size (dbh) classes and could be readily described with a standardized normal distribution, and (2) the distribution was somewhat skewed (positive) for smaller size classes, but not enough to prohibit use of the bivariate normal methodology. Therefore, the distribution of BAG5YR for a given growth period and size of tree can be defined if its mean and variance are known. The mean BAG5YR for a given tree size can be estimated with the mean model—equations (3) and (5). A general linear model computer program was used to develop an equation that predicts the standard deviation for a given tree size. The data were first divided into DBH, SI, $\overline{D}$, and PS classes, and the standard deviation of BAG5YR was calculated for each class. The resulting regression equation used to estimate the standard deviation for a given tree size, $\hat{\sigma}_{ij}$,

$$\hat{\sigma}_{ij} = 0.00915129 \cdot EXP(0.23639572\ DBH_{ij}) \quad (6)$$

had a calculated r^2 value equal to 0.67. SI, $\overline{D}$, and PS did not significantly reduce the variation so they were not included in the model. Equation (6) is plotted in Figure 9.

Individual-tree growth for a given period can be randomly estimated with equations (3), (5), and (6) in the following manner: (1) generate a random number, Z, from a normal distribution with mean = 0 and variance = 1, and (2) recognizing that $Z = (X - \mu)/\sigma$, convert Z to the predicted basal-area growth for the 5-year period (X_{ij}):

$$X_{ij} = Z \cdot \hat{\sigma}_{ij} + BAG5YR_{ij} \quad (7)$$

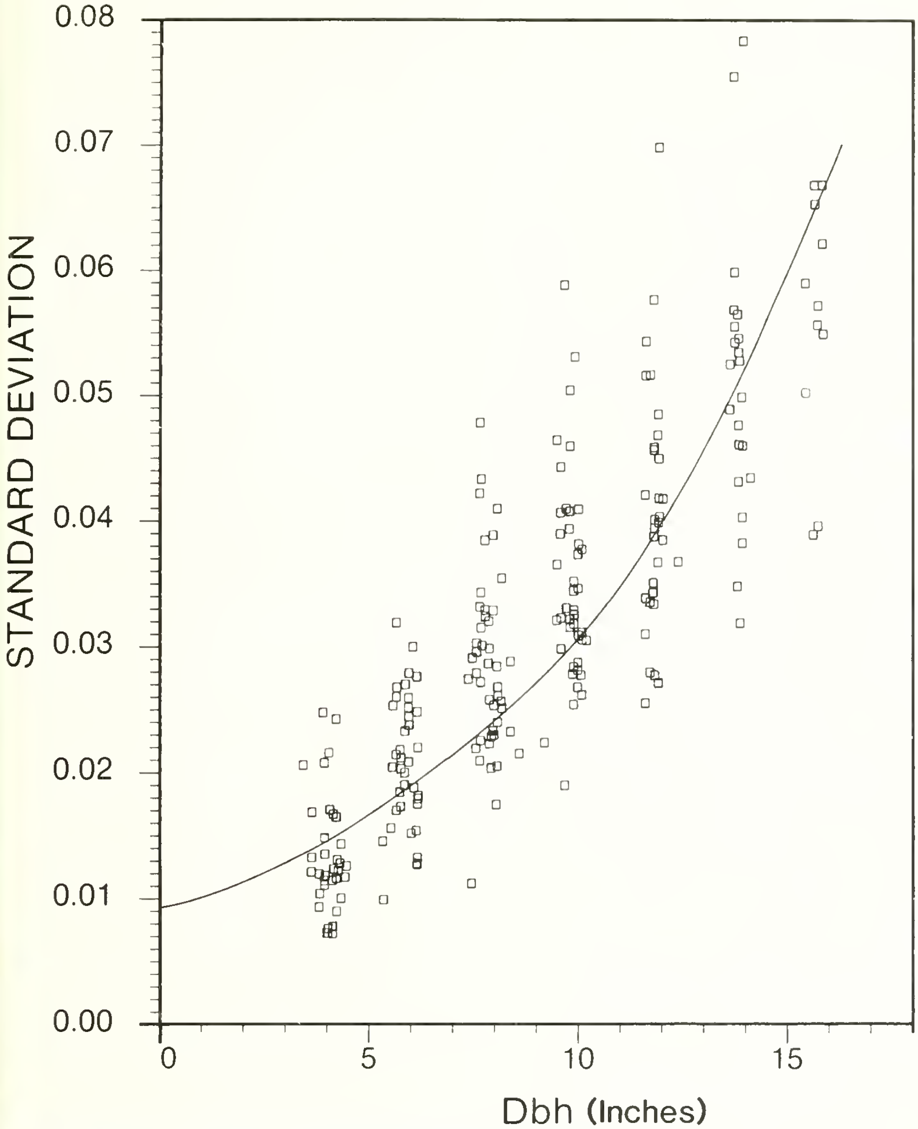

Figure 9.—Scatter plot of standard deviations over DBH ($\hat{\sigma}$ = 0.00915129 • EXP (0.12639572 DBH_{ij}), calculated r^2 = 0.67).

In other words, the predicted 5-year basal-area growth for an individual tree is randomly selected from the distribution of basal-area growth about the mean for that size tree.

Randomly selecting the growth at successive growth periods would not be realistic unless the selection procedure were "tied together" in some fashion. If a bivariate normal distribution between two successive growth periods for a *given dbh class* is assumed, the *conditional mean* of the predicted 5-year basal-area growth for the i-th tree in the j-th stand for the k-th growth period, $(Y_{ij})_k$, *given* that the value of the growth from the previous period was $(X_{ij})_{k-1}$, is

$$(Y_{ij})_k = (BAG5YR_{ij})_k + \hat{\varrho}[(\hat{\sigma}_{ij})_k/(\hat{\sigma}_{ij})_{k-1}] \cdot [(X_{ij})_{k-1} - (BAG5YR_{ij})_{k-1}] \quad (8)$$

for k = 2 through n successive growth periods of interest. The quantity $\hat{\varrho}$ represents the correlation between basal area growth for successive growth periods for a given dbh class. Extensive plotting of the data and regression analyses revealed that variations in $\hat{\varrho}$ could not be explained with SI, $\overline{D}$, or PS. Values of $\hat{\varrho}$ did not differ significantly between successive growth periods either. An overall mean value of 0.632 was therefore used for $\hat{\varrho}$.

The standard deviation, $(S_{ij})_k$, about the conditional mean growth, $(Y_{ij})_k$, in equation (8) is

$$(S_{ij})_k = (\hat{\sigma}_{ij})_k(1 - \hat{\varrho}^2)^{0.5} \quad (9)$$

The value of *predicted* growth for the first growth period, $(X_{ij})_1$, is determined by random selection as in equation (7). The value of $(X_{ij})_k$ for $k > 1$ is determined by first generating a random number, Z, from a normal distribution with mean = 0 and variance = 1, then using (8) and (9) to convert Z to the predicted basal area growth:

$$(X_{ij})_k = Z \cdot (S_{ij})_k + (Y_{ij})_k \quad (10)$$

The random-selection component in the random model allows trees to change position. However, inspection of equation (8) reveals the desirable feature of the bivariate normal approach—the probability is high that fast-growing trees will remain fast growers and slow growers will remain slow growers.

Random/Known Model

The random/known model is identical to the random model except that the first 5-year growth, $(X_{ij})_1$, is known from past measurements. If $(X_{ij})_1$ is known rather than randomly selected, position changes of trees in the stand are more likely to parallel actual changes. Unfortunately, actual 5-year growth records are seldom known in practice. However, when they are known, they should be used to the fullest extent.

Testing the Models

Test Procedures

The r-square values reported earlier are one measure of how well component equations fit appropriate data sets. However, component equations for each model ultimately must be combined to predict tree growth rates which are summed to obtain stand growth and yield estimates. For this reason I used plot basal areas per acre to evaluate the performance of each model. The models were evaluated on the data used to construct the models because independent data sets were not available. The data used in this study also represent the most extensive records available for managed upland oak stands. Using the same data set for testing does not guarantee that the models will perform well because each model component was developed independently. Errors for each component could very well be cumulative.

Table 1.—Actual and predicted 5-year basal-area growth rates per acre; growth rates (ft^2/acre) and differences are averages for 77 permanent plots (standard deviations in parentheses)

Growth period	Growth		Difference (predicted-actual)	Percentage difference[a]
	Actual	Predicted		
		MEAN MODEL		
1	7.21	8.16	0.95** (2.26)	16.22* (58.82)
2	6.58	6.65	0.08[NS] (1.54)	7.43[NS] (42.82)
3	11.58	10.63	−0.95** (1.95)	−7.30** (18.50)
Total	25.37	25.45	0.08[NS] (3.59)	2.26[NS] (17.84)
		RANDOM MODEL		
1	7.21	8.24	1.03** (2.24)	16.49* (59.49)
2	6.58	6.81	0.23[NS] (1.58)	10.12* (43.30)
3	11.58	10.90	−0.68** (2.01)	−5.08* (19.21)
Total	25.37	25.95	0.58[NS] (3.66)	3.88[NS] (18.51)
		RANDOM/KNOWN MODEL		
1	7.21	7.21	—	—
2	6.58	6.63	0.05[NS] (2.13)	8.51[NS] (60.53)
3	11.58	10.65	−0.93** (2.37)	−7.33** (21.66)
Total	25.37	24.49	−0.88[NS] (4.18)	−6.36[NS] (30.32)

[a]Percentage difference is the average of the percentage differences for 77 plots. It does not equal the percentage difference of the average from columns two and three.

NS = not significant; * = significant at α = 0.05; ** = significant at α = 0.01.

All trees larger than 2.5 inches dbh in 1962 were used to test the growth models from 1962 to 1977. The equations developed in this study were applied to all trees in the tree list, regardless of species. Each plot was first "grown" for one 5-year period. Dead or cut trees were removed from the list and the stand attributes $\overline{D}$ and PS were then updated for input into the next 5-year growth projection. Three 5-year projections were made with the mean and random models, but only two with the random/known model because the first growth period is given.

Since the mean model is deterministic, only one computer run was necessary to obtain the growth predictions. The random models, on the other hand, are stochastic, so growth predictions depend somewhat on the random numbers that are generated. Ten computer runs were made for both the random and random/known models, and the results were averaged to obtain the growth predictions. Also, when the random and random/known models are used, the basal-area growth distribution for a given size class can include values less than zero. Since negative growth rates are not realistic, they were set equal to zero before the next 5-year growth prediction.

Test Results

Average actual and predicted basal-area growth and yield values per acre are shown in Tables 1–2 for the 77 growth plots at each growth period. Since the growth rates are indicative of *net* growth, yield values in Table 2 can be determined by adding the growth rates in Table 1 except for the last 5-year period when cutting occurred.

Differences and percentage differences between actual and predicted growth rates and yields were tested for significance (from zero) using t-tests at the end of each growth period, and also at the end of the entire growth projection. The

Table 2.—Actual and predicted basal-area yields per acre; yields (ft²/acre) and differences are averages for 77 permanent plots (standard deviations in parentheses)

Years after initial measurement	Basal area/acre		Difference (predicted-actual)	Percentage difference[a]
	Actual	Predicted		
		MEAN MODEL		
0	51.41	51.41	—	—
5	58.62	59.57	9.95** (2.26)	1.01NS (4.74)
10	65.20	66.23	1.03** (2.66)	1.24* (4.75)
15	72.79	72.49	−0.30NS (3.33)	−0.78NS (5.85)
		RANDOM MODEL		
0	51.41	51.41	—	—
5	58.62	59.65	1.03** (2.24)	1.12* (4.72)
10	65.20	66.46	1.25** (2.66)	1.56** (4.76)
15	72.79	72.95	0.16NS (3.37)	−0.20NS (5.90)
		RANDOM/KNOWN MODEL		
0	51.41	51.41	—	—
5	58.62	58.62	—	—
10	65.20	65.25	0.05NS (2.13)	0.34NS (3.37)
15	72.74	71.75	−1.03* (4.11)	−1.14NS (5.74)

[a]Percentage difference is the average of percentage differences for 77 plots; it does not equal the percentage difference of the averages from columns two and three.
NS = not significant; * = significant at $\alpha = 0.05$; ** = significant at $\alpha = 0.01$.

percentage differences and their corresponding standard deviations provide perhaps the "clearest" view of model performance. For example, the percentage difference in growth for the mean model for the third growth period was -7.30 percent $\pm$ 18.50 percent. These values indicate that, on the average, growth was estimated 7.30 percent low for the 77 plots, and that 67 percent (one standard deviation) of the predicted growth rates for *given* stands (plots) can be expected to fall between 25.8 percent low and 11.2 percent high.

Inspection of Tables 1-2 reveals an important fact about the growth projections—short-term projections can result in predicted values that are significantly different from actual values. In general, the predicted growth rates were too high for the first two growth periods and too low for the third 5-year period. However, total growth for the entire projection period was not significantly different from actual growth. Yields also were significantly different until the final growth period was completed.

On the basis of the data, I believe that the inability to make accurate short-term projections can be attributed mostly to one unpredictable variable not included in growth models—weather. The growth models were constructed with data from all three growth periods, so the weather effects were essentially "averaged" into the model parameters. The best we can do at the present time is to make growth predictions for "average" weather conditions, and be somewhat cautious in using growth models for very short-term projections.

Two other factors contribute to the differences between predicted and actual values: (1) all trees, regardless of species, were "grown" with the models developed for oaks only, and (2) 27 of the 77 plots received a second thinning before the third growth period. The first factor probably is of little consequence because most of the trees were oaks. However, separate growth models for other species such as hickory and dogwood undoubtedly would increase the overall accuracy of the predictions. The effects of repeated thinnings in oak stands have not been investigated, but growth models that allow for effects of repeated thinnings also would undoubtedly increase overall accuracy. The effects of repeated thinnings are beyond the scope of this paper —the assumption made here is that similar stands will respond the same, regardless of the number of thinnings.

Overall, all three growth models performed well. Growth was estimated within 2 to 6 percent of the actual growth for the entire growth projection period, $\pm$ 17 to 30 percent. Yields were within 1 percent, $\pm$ 6 percent. The random/known model performed slightly worse than the other models even though the actual growth for the first period was included. This result occurred because of the weather effects noted previously—predicted values only had two growth periods to "average" out.

Scatter plots of the residuals (predicted-actual) against SI, $\bar{D}$, and PS revealed no biases for these variables. The only trend apparent in the plots of the residuals was that plots with low actual growth were overestimated, and those plots with high growth were underestimated.

Mean stand diameters also were calculated at the end of each growth period (Table 3). All three models projected the mean stand diameter well.

Table 3.—Actual and predicted mean stand diameters ($\bar{D}$), based on averages for 77 permanent plots

Years since initial measurement	Actual $\bar{D}$	Mean model	Random model	Random/known model
		Inches		
0	7.05	7.05	7.05	7.05
5	7.77	7.83	7.83	7.77
10	8.41	8.46	8.47	8.40
15	9.46	9.42	9.44	9.37

Discussion and Conclusions

The diameter growth models developed in this study are for use primarily as a component part of an individual-tree growth simulator for upland oak stands. A mortality model now being developed that removes trees from the tree list is required before the simulator can be used to project future growth and yield estimates. However, the diameter growth models can be functional at the present time if the user has access to mortality estimates and can distribute the mortality throughout the tree list. Short projections (5 to 10 years) probably can be made if no mortality is assumed. Fractional portions of the 5-year projections can be made by linear interpolation.

Since all three growth models performed well, which model should be used? Obviously, the mean model must always be used because it is a component of both the random models. However, the mean model is recommended *only* when the user does not have access to a high-speed computer. Equations (3) and (5) can be be easily programed in a programable calculator to obtain quick estimates of tree growth for office and field applications. If a high-speed computer —almost essential for making projections with individual-tree growth simulators—and the past 5 years' growth are available, then the random/known model is recommended. If past growth is unknown, as it usually is, then the random model should be used. Care should be exercised in selecting a reliable random number generator that is unbiased when using the random models.

Computer programs written in BASIC or FORTRAN for all three models are available from the author upon request. However, the user is encouraged to write his own programs to ensure the desired program flexibility.

Test results in this study indicated that all three growth models predicted stand basal-area growth and yields satisfactorily. These results indicate how well the growth models perform as an aggregate of the individual-tree growth projections. However, since we are also interested in the species and size class of individual trees, the distribution of the trees in the projected stand warrants investigation. Even though the distribution parameters were not modeled directly, we do not want the projected distribution to spread too much or too little. As an example, the distribution of trees for all three growth models after three 5-year projections was determined for one plot (stand) only (Fig. 10). The site index on the plot was 70 and the mean stand diameter was 4.31 inches after thinning in 1962. Stocking was reduced to 53.04 percent in 1962, and a second thinning in 1972 lowered the percent stocking from 77.46 to 67.09 percent. Figure 10 shows that the projected distribution for the random/known model most closely approached that of the actual distribution in 1977. The mean and random model distributions were too high near the mean. Chi-square tests in which the numbers of trees by 1-inch diameter classes were used were not significant for the random/known distribution, but were significant for the other two models.

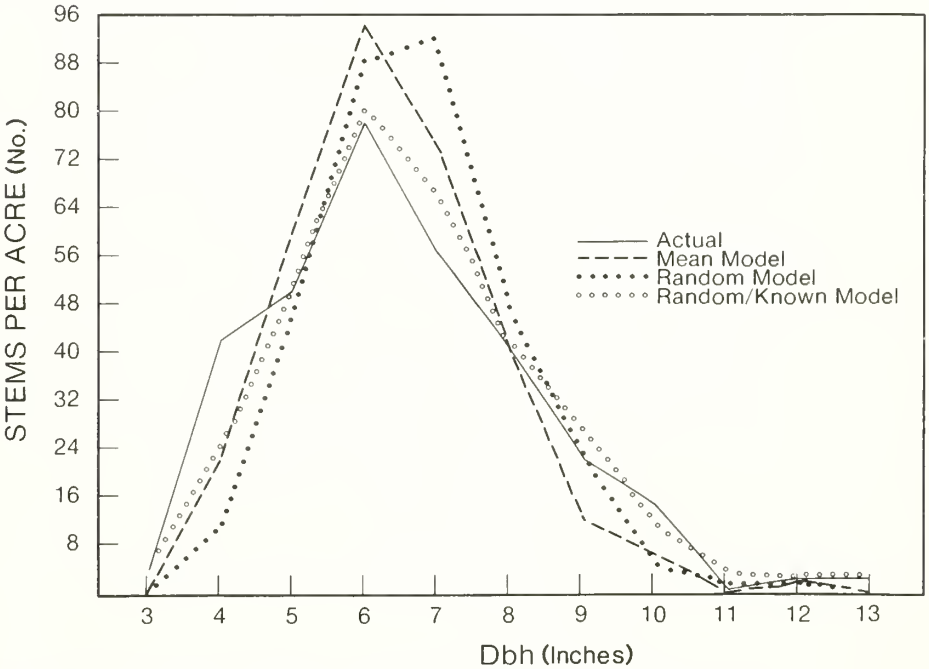

Figure 10.—Actual and predicted diameter distributions for one stand (plot) in 1977 after 15 years' growth.

The order of the largest 15 trees on the plot in 1977 is shown in Table 4. The change in the rankings for the actual diameters from 1962 to 1977 demonstrates the dramatic changes that occur within a given stand. We are probably demanding too much of an individual-tree diameter growth model if we also expect the rankings to be predicted accurately. However, investigation of the resulting rankings can be informative. Spearman rank correlation tests revealed that only the random/known model rankings were not significantly different from the actual rankings in 1977.

Distribution and rank tests are important indicators of model performance, but they are also costly and time consuming. Since the inclusion of the mortality model also affects the distribution and rank of trees, extensive testing in these areas for all plots is better left until the complete individual-tree growth simulator is developed.

Table 4.—Actual and predicted ranks of largest 15 trees for one stand (plot) in 1977 after 15 years' growth

Actual rank 1962	Actual dbh 1977	Actual rank 1977	Predicted rank in 1977		
			Mean model	Random model	Random/known model
1	12.6	1	1	1	1
3	12.0	2	3	2	2
7	10.2	3	7	19	3
2	10.1	4	2	6	4
10	10.0	5	10	12	5
5	10.0	6	5	4	12
6	9.9	7	6	8	9
4	9.9	8	4	11	7
11	9.8	9	11	28	8
8	9.5	10	8	10	14
14	9.4	11	14	17	11
29	9.4	12	29	39	6
16	9.2	13	16	16	10
20	9.1	14	20	13	13
35	9.1	15	36	50	20

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Hilt, Donald E. **Individual tree diameter growth model for managed, even-aged, upland oak stands.** Res. Pap. NE-533. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 15 p.

A distance-independent, individual-tree diameter growth model was developed for managed, even-aged, upland oak stands. The 5-year basal-area growth of individual trees is first modeled as a function of dbh squared for given stands. Parameters from these models are then modeled as a function of mean stand diameter, percent stocking of the stand, and site index. A stochastic option for the overall model also was developed. Tests on data from managed stands revealed that the model performed well.

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Keywords: Distance-independent; stochastic; thinning

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Precommercial Crop-Tree Release Increases Diameter Growth of Appalachian Hardwood Saplings

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Abstract

Codominant seedling-origin crop trees 25 to 39 feet tall in even-aged, precommercial-size hardwood stands were released in West Virginia. Trees were located on two sites: good oak site index 75 and fair oak site 63. Species studied were black cherry, sweet birch, and yellow-poplar. Three-year results indicated that the trees generally responded to release; the 3-year dbh growth of released trees was 0.2 to 0.4 inch greater than that of unreleased trees. Height growth did not increase.

Introduction

Many forest managers are concerned about selecting and releasing crop trees in young, even-aged hardwood stands. They want to know when and how to release crop trees, the cost, and the benefits of a crop-tree release.

Crop trees are released to:

1. Maintain the selected crop trees in at least a codominant crown-class position until maturity.

2. Manipulate composition by eliminating unwanted trees or species.

3. Stimulate dbh and, if possible, increase the merchantable and total height of crop trees.

4. Increase the quality of the residual stand by putting accelerated growth on the better trees.

5. Reduce the rotation length of the stand.

Generally, crop-tree release is applied as an individual-tree treatment in precommercial-size stands, though crop trees also can be released on a stand basis. When crop trees are selected, several trees per acre are chosen, and some or all of the remaining noncrop trees in the area are removed. Usually, trees are removed from the upper crown canopy to the lower canopy.

Positive results from the application of crop-tree release techniques in young hardwood stands have been reported (Table 1). Ten years after an intensive cleaning in 11-year-old mixed hardwood stands, Della-Bianca (1975) found that differences in dbh growth rates were greatest the first 3 years after release; there were no differences in growth response between the 6th and 10th year. However, growth response has been inconsistent for released crop trees in young stands less than 10 years after clearcutting. Crop-tree recommendations range from questionable to no release for many hardwood species (Table 2).

Table 1.—Positive responses in young even-aged stands from crop-tree release techniques

Species	Stand age	Treatment	Source
Northern hardwoods	13–18	12- to 15-foot tree spacing	Church 1955
Sugar maple, white oak, yellow-poplar	7–14	3-foot crown	Downs 1946
Sugar maple, elm, white ash, basswood	11	5-foot bole	Stoeckler and Arbogast 1947
Northern hardwoods	11	2½- and 5-foot bole	Conover and Ralston 1959
Red maple	7	5-foot bole	Trimble 1974 Smith 1977
Upland hardwoods	6	Stand area	Boyette and Brenneman 1978
Yellow birch	7	8-foot crown	Erdmann et al. 1981
Mixed hardwoods	11	Free to grow	Della-Bianca 1975
Sweet birch, yellow-poplar, black cherry	10	Free to grow	Smith 1981
Appalachian hardwoods[a]	7–12	Free to grow	Lamson 1983

[a]Yellow-poplar, basswood, red maple, black cherry, northern red oak stump sprouts.

Table 2.—Crop tree recommendations ranging from questionable to no release in young even-aged stands

Species	Stand age after clearcutting	Treatment	Source
Red oak, yellow-poplar, black cherry, sugar maple	9	5-foot bole	Smith 1979
Red oak, yellow-poplar, black cherry	7	5-foot bole	Trimble 1973 Smith 1979
Yellow-poplar	6	Free to grow	Beck 1977
Central hardwoods[a]	8	Stand area	Hilt and Dale 1982

[a]Thinned 8, 10, 17, and 22 years after clearcutting; stocking levels were 30, 50, and 70 percent.

Hilt and Dale (1982) used residual stocking levels of 30, 50, and 70 percent in applying a precommercial thinning to hardwood stands 8 years after clearcutting (Table 2). The 30- and 50-percent stocking levels certainly approached the intensity of a crop-tree release, but these treatments did not significantly increase growth. The authors did not recommend thinning. However, in practice, a thinning is different from a crop-tree release. In a thinning, cutting begins primarily in the lower crown classes to harvest the trees that are going to die. In a crop-tree release, cutting begins with trees in the upper crown to provide more growing space for the better trees in the stand. One possible reason for some of the variation in research results (Tables 1 and 2) is that many studies do not include a measure of the degree of release around the crown margin of the crop tree.

In older stands, the diameter-growth response to crop-tree release has been more consistent. Drinkwater (1960) reported a positive response for sugar maple, *Acer saccharum* Marsh., released to a 4- to 10-foot crown margin 25 years after clearcutting. Stone (1977) found positive results when releasing sugar maple trees 50 years after clearcutting to a 5- to 10-foot crown margin. Marquis (1969) reported successful response in 25-year-old, even-aged stands of northern hardwood crop trees released to a free-to-grow crown position. Erdmann and Peterson (1972) and Erdmann et al. (1975) successfully released yellow birch, *Betula alleghaniensis* Britton, to a 10- to 14-foot and 5-foot crown margin 40 and 65 years after clearcutting. Generally, dominant-codominant crop trees have responded well to release. Sugar maple, yellow-birch, mixed southern Appalachian hardwoods, and Appalachian hardwood stump sprouts have shown the best response.

In this paper, we report 3-year results of releasing of sapling-size trees in precommercial-size stands. These results are for central Appalachian hardwood species.

The study was established on the Fernow Experimental Forest near Parsons, West Virginia. The elevation of the study area ranges from 2,300 to 2,500 feet; slopes range from flat to very steep (60 percent). Soils are medium textured and well drained, and are derived from sandstone and shale. The Experimental Forest has a cool climate with a well-distributed annual rainfall of about 60 inches.

From about 1905 to 1910, the study area was logged by a high-grading technique. The second-growth stand was about 55 years old when the stand was clearcut, that is, all trees 1.0 inch and larger in diameter at breast height (dbh) in the study area were cut. The study was done on two oak sites. The good oak sites had an average site index of 75 and the fair sites averaged 63. The most numerous sawlog-size species on the good sites were sugar maple; yellow-poplar; northern red oak, *Quercus rubra* L.; basswood, *Tilia americana* L.; hickory, *Carya* spp.; American beech, *Fagus grandifolia* Ehrh.; and sweet birch, *Betula lenta* L. On the fair sites, the primary species were chestnut, *Castanea* spp.; white oak, *Quercus alba* L.; northern red oak; red maple, *Acer rubrum* L.; sweet birch; black gum, *Nyssa sylvatica* Marsh.; sassafras, *Sassafras albidum* (Nutt.) Nees.; and sourwood, *Oxydendrum arboreum* (L.) DC.

Trees on the good sites were released 10 and 12 years after clearcutting; trees on the fair site were released 11 years after clearcutting. However, in this study total height at time of release was used to decide when to release crop trees. Crop trees were divided into two height classes: trees 25 to 32 feet tall and those 33 to 39 feet. No study crop trees were influenced by the perimeter border of the clearcuts.

All study crop trees were codominant at the time of treatment and were either released to a free-to-grow position or were not released. Crop trees of seedling origin (no visible stump present) were selected on the basis of superficial quality, including no prominent stem fork, a vigorous crown, no wounding or exposed sapwood, and no visible rot. For each species evaluated, about 15 to 20 crop trees were initially selected for each treatment within each height category. The exceptions were 33- to 39-foot trees on the fair sites, where fewer trees were available for sampling.

On the good sites, yellow-poplar, black cherry, and sweet birch were the selected species; sweet birch and black cherry were selected on fair sites. Oaks were not selected because there were no codominant seedling-origin trees on the good sites, and on the fair sites, the oaks were predominantly of sprout origin. Evaluated variables included change in crown-class position, total height, and dbh. Analysis of variance with unequal samples was used to test whether the average dbh and height responses of the released crop trees differed from those of the unreleased (control) crop trees.

Crop trees were released by a crown-touching technique (Fig. 1). Any tree adjacent to the crop tree was cut if its crown touched the crown of the crop tree or if the crown was above or below the drip line or edge of the crop-tree crown. A majority of the crop trees were released on four sides of the crown; the remaining trees were released on three sides. After release, the crown margins of adjacent trees were about 4 feet from the crop-tree crown margin but this distance was quite variable, especially where crop trees were near each other. Trees were cut with a chain saw and stumps were not treated with herbicides. Manhours required to select and release crop trees were recorded for more than 1,000 crop trees. The chain-saw operator did not select trees for release as crop-tree selection was a separate operation.

Three growing seasons after treatment, there was a severe snowstorm during October when the trees were in full foliage. Many of the crop trees had broken tops, were bent over, or were uprooted. Also, many released crop trees were rereleased and control trees were released. The study was terminated after three growing seasons.

Figure 1.—A 25- to 32-foot crop tree before (left) and after release (right).

Results

Crop-Tree Height Class 25 to 32 Feet

Total height.—In general, within each species and site class, there were no significant differences between the height-growth means for released and control trees. The exception was for yellow-poplar on the good site, where the average 3-year growth of released trees was greater than that of the control trees (8.2 versus 5.7 feet, Table 3). There were no differences in height growth between released and control trees for the other species on the good site, and a difference of only about 0.5 foot on the fair site. For the three species released on the good site, the average 3-year height growth ranged from 7.7 to 8.8 feet. On the fair site, the 3-year height growth for the released trees was between 6.3 and 6.4 feet for the two species (Table 3). Since height growth was not measured on damaged trees from the October snow, lack of significance between treatment means may have been due to a small sample size.

Dbh.—In all instances, the average 3-year dbh growth for the released crop trees was significantly greater than for control trees (Table 3). The initial dbh for all crop trees before treatment ranged from 2.3 to 3.0 inches. The 3-year response for all species, treatments, and site classes ranged from 0.9 to 1.6 inches (Table 3). Yellow-poplar had the best response followed by black cherry; sweet birch was a distant third.

Differences in 3-year dbh growth for the released compared with control trees was at least 0.2 inch for yellow-poplar and sweet birch on the good and fair sites. Maximum growth was 0.4 and 0.3 inch for black cherry on the good and fair sites, respectively (Table 3).

Crop-Tree Height Class 33 to 39 Feet

Total height.—As was generally true for the lower height classes, there was no significant difference in height-growth response between released and control treatments. On the good sites, 3-year height growth for all species ranged from 7.2 to slightly more than 8.2 feet; on the fair site the range was about 5.9 to 7.2 feet (Table 3). Because of the snowstorm, the sample size was marginal for this height category on the good sites and for sweet birch on the fair sites.

Dbh.—On the good sites, the average dbh for all trees before release ranged from 3.2 to 3.8 inches; on the fair site, the initial dbh was 2.7 to 3.2 inches. On the good sites, the release crop trees for all species had significantly larger 3-year dbh growth than the control trees. This dbh growth ranged from 1.2 to 1.6 inches with the difference between release and control trees averaging 0.2 inch for yellow-poplar and 0.4 inch for black cherry. On the fair sites, black cherry growth was better than sweet birch growth, but the difference between release and control crop trees was not significant (Table 3).

Regression of Crown Class

The regression of crown class from a dominant-codominant position to an intermediate-overtopped position has been of concern in precommercial-size, even-aged hardwood stands where crop-tree release techniques have been applied. In this study, crown classes generally remained stable after release (for the 3-year period). Of the total of 223 study trees, including all species, release treatments, heights, and site categories, only 12 trees regressed in crown class and 6 of these were yellow-poplar control trees. Of the 112 release trees in the study, only 3 regressed in crown class. Thus, crown-class regression did not appear to have a significant influence on the study trees 3 years after treatment.

Cost of Selecting and Releasing Crop Trees

On the average, 47 crop trees were selected per manhour. The flagged crop trees were selected from thirty-six ½-acre openings, each averaging about 29 crop trees. Premarked crop trees were released with a chain saw and an average of 30 trees were released in 1.6 manhours. At a rate of $6 per manhour, it would cost about $19.20 to release an average of 60 crop trees per acre. At the same rate per manhour, the cost of selecting 60 crop trees before release would be about $7.70 per acre. Travel time to and from the area is not included.

Table 3.—Three-year total height and dbh growth for released and unreleased crop trees

Species and treatment	Total height (feet)			Dbh (inches)		
	Initial	3-year	Difference	Initial	3-year	Difference
			TREES 25.0 TO 32.9 FEET TALL			
Good Oak Sites						
Sweet birch						
Release	28.3 (26)[a]	36.0 (12)	7.7ns	2.3 (26)	3.4 (25)	1.1**
Control	28.1 (26)	35.8 (17)	7.7	2.4 (26)	3.3 (26)	0.9
Yellow-poplar						
Release	28.2 (21)	36.4 (8)	8.2**	2.7 (21)	4.3 (21)	1.6**
Control	29.6 (26)	34.3 (10)	5.7	3.0 (26)	4.4 (26)	1.4
Black cherry						
Release	28.7 (26)	37.5 (10)	8.8ns	2.5 (26)	3.9 (24)	1.4**
Control	29.1 (17)	37.9 (5)	8.8	2.6 (17)	3.6 (17)	1.0
Fair Oak Sites						
Sweet birch						
Release	29.4 (26)	35.8 (25)	6.4ns	2.4 (26)	3.5 (26)	1.1**
Control	30.0 (25)	36.9 (25)	6.9	2.5 (25)	3.4 (15)	0.9
Black cherry						
Release	30.5 (17)	36.8 (19)	6.3ns	2.5 (17)	3.8 (17)	1.3**
Control	30.0 (13)	36.6 (11)	6.6	2.5 (13)	3.5 (13)	1.0
			TREES 33.0 TO 39.9 FEET TALL			
Good Oak Sites						
Yellow-poplar						
Release	36.4 (20)	44.0 (7)	7.6ns	3.6 (22)	5.2 (20)	1.6**
Control	35.7 (19)	42.9 (6)	7.2	3.8 (20)	5.2 (19)	1.4
Black cherry						
Release	36.5 (16)	43.8 (7)	7.3ns	3.4 (17)	5.0 (16)	1.6**
Control	36.3 (15)	44.5 (6)	8.2	3.2 (18)	4.4 (15)	1.2
Fair Oak Sites						
Sweet birch						
Release	34.0 (7)	39.9 (5)	5.9ns	2.7 (7)	3.7 (7)	1.0ns
Control	35.2 (10)	41.2 (9)	6.0	2.9 (10)	3.8 (10)	0.9
Black cherry						
Release	35.3 (12)	42.5 (11)	7.2ns	3.2 (13)	4.7 (12)	1.5ns
Control	35.0 (13)	42.1 (13)	7.1	3.2 (13)	4.6 (13)	1.4

[a]Number of trees in parentheses.
**Means significantly different at 1-percent level.
ns = not significant

Discussion

In this study, codominant crop trees 25 feet or taller produced a significant dbh-growth response when the crown-touching method was used. For all tree species and height classes evaluated, except for 33- to 39-foot-tall sweet birch and black cherry on the fair sites, release trees had significantly higher dbh growth than the control trees. Releasing crop trees increased 3-year dbh growth from 0.2 to 0.4 inch over the control trees. In reporting 5-year results, Lamson (1983) found that releasing stems of stump sprout origin 7 and 12 years after clearcutting produced a significant positive dbh-growth response.

In general, the released seedling-origin trees in this study did not produce a significant height-growth response compared with the control trees; this also was true for the trees of stump sprout origin in Lamson's study.

In previous studies with younger trees, crown-class regression has been of major concern (Trimble 1973, 1974; Smith 1979). During this 3-year study period, crown-class regression apparently was not promoted by crop-tree release as it occurred in only 3 of 112 codominant release crop trees. It may be that these 10- to 12-year-old trees are not responding as rapidly as younger trees because the study was not long enough to allow regression to develop, or that the trees at this height are beginning to decelerate in height growth. Or it may be that as the trees become taller, there is more crown stability, so that crown class is easier to retain than in younger stands. Or perhaps the seedlings at this 10- to 12-year period after clearcutting are similar to sprouts. In a West Virginia study, Wendel (1975) reported that the dominant stump sprout in a clump did not remain the same from year to year; about 50 percent of the red oak stumps had changes in dominant sprouts during the first 5 years. Twelve percent of the red oak sprouts changed dominant position from 7th to the 10th year. In general, as the years increased, the changing of dominating red oak sprouts decreased. This seedling-origin study has been terminated so it cannot be determined whether crown-class regression would have become more apparent over a longer period.

Although the crown-touching techniques resulted in a positive dbh-growth response, it is not known how long this response would have been maintained. More definite information about the degree of release is needed to develop better guidelines. On the basis of these results and general observations, we believe that the crown-touching treatment should be used as a minimum release treatment. More research is needed on applying these methods to a variety of hardwood tree species on an individual-tree and stand basis. If precommercially released trees consistently grow larger in average dbh than nonreleased trees, does this diameter increase at an early age result in the released trees maturing at a significantly earlier age than nonreleased trees? If true, this could result in shorter rotations, and with shorter rotations, economic evaluations may become more favorable to applying crop-tree release treatments. Thus, researchers need to determine the cost and evaluate the growth response and benefits from each release treatment, and then develop guidelines that are easy to understand and apply.

The following suggestions for releasing crop trees in young central Appalachian hardwood stands are based on this and other studies.

- Do not release more than 50 to 75 crop trees per acre. Crop trees are expensive to release. The spacing between crop trees should be at least 25 to 30 feet. Also, additional crop trees could become available from current noncrop trees.
- Cut or remove all adjacent trees that are touching the crown of the crop tree or that are above or below the drip line or edge of the crop-tree crown. Cut all questionable trees. Where there are two excellent crop trees beside each other, retain both trees.
- Select crop trees from among the high-quality, vigorous, desirable tree species. It is better not to release a crop tree or crop trees in part of the stand than to release an obvious unacceptable tree to meet goals for spacing or number of trees per acre.
- Cut only trees whose removal benefit the crop tree. Do not cut "weed" or undesirable tree species throughout the stand unless this is part of the release objective.
- For intolerant species, release only trees in the dominant or codominant crown class.
- For sprout clumps, cut all but the best one or two widely spaced (U-shaped attachment), high-quality, dominant-codominant, low-origin sprouts less than 6.0 inches above the ground (Lamson 1983).
- The earliest probable time when crop trees should be released by the techniques we used is when the codominant trees in the stand have attained a height of about 25 feet.
- In precommercial-size stands with grapevines, delay crop-tree release for about 5 years after the grapevines have been cut. Shading kills the grapevine stump sprouts and if a release and grapevine control cutting is done simultaneously, grapevine sprouting can be stimulated. This recommendation depends on the average height of the trees in the stand or the use of herbicides. As trees become taller and shading increases, the delay in releasing crop trees after a grapevine treatment becomes less important. Grapevines could be treated with herbicides during crop-tree release, but a herbicide application could present a risk to the crop tree.

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Smith, H. Clay; Lamson, Neil I. Precommercial crop-tree release increases diameter growth of Appalachian hardwood saplings. Res. Pap. NE-534. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 7 p.

Hardwood, codominant sapling crop trees 25 to 39 feet tall in even-aged stands were released in a West Virginia study. Trees were located on two oak sites: good oak site index 75 and fair oak site 63. Species studied were black cherry, sweet birch, and yellow-poplar. Three-year results indicated that the trees generally responded to release; the 3-year dbh growth of released trees was 0.2 to 0.4 inch greater than that of unreleased trees. Height growth did not increase.

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Keywords: Release, crop trees, Appalachian hardwoods, dbh response

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Silvicultural Guide for Paper Birch in the Northeast (revised)

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Abstract

This revised guide provides practical information on silvicultural treatments to grow paper birch as a timber crop. It covers treatments for existing stands, the regeneration of new stands, and subsequent culture to maturity. The stocking chart has been revised to reflect results of current growth studies.

Introduction

Paper birch has long been prized for its smooth grain and texture, dimensional stability, and capacity for turning and shaping. The numerous small mills scattered throughout the range of paper birch in northern New England rely heavily on this species for the manufacture of numerous items—from toothpicks and pool cues to brush handles, and covers for cosmetic bottles. Because supplies of high-quality birch near these mills are becoming depleted, wood must be transported over longer and longer distances. These conditions drive up the price for birch, which at times is of marginal quality. This guide, a revision of that developed for paper birch by Marquis et al. 1969, describes intensive silvicultural practices that land managers can use to grow high-quality paper birch crops in the shortest possible time. I describe treatments for existing stands with little or no previous silvicultural treatment, the establishment of new stands, and a schedule of treatments from early age to maturity.

Paper birch does respond to treatment. In the greenhouse, with favorable nutrient and moisture supplies, we have grown paper birch to a height of 16 feet and a diameter of 1 inch in 9 months. This growth rate may not be possible under field conditions, but it does indicate the biological potential of paper birch to respond to favorable environmental conditions.

The economics of paper birch growth also are favorable. Since relatively small trees—8 to 10 inches for boltwood and 12 to 14 inches for sawlogs—can be used, a relatively short rotation of intensive treatments can be justified. Land managers can expect a payoff from intensive silvicultural practices in less than 2 decades, as opposed to the many decades required for merchantable size softwoods and many of the other hardwoods. In 1980, the value of paper birch at mills in New Hampshire ranged from $105 to $350 per thousand board feet for sawlogs and veneer, $70 to $106 per cord for boltwood, and $50 to $70 per cord for firewood.

We anticipate that the application of the cultural measures described in this guide from the time of regeneration to final harvest will reduce sawlog rotation length by half. And working in current stands of pole and near boltwood size will reduce the rotation by several decades.

Paper Birch—The Species

Under natural conditions, paper birch is a pioneer or early successional species. It is intolerant of shade and competition from older trees, woody shrubs, and herbaceous species. Large, pure stands originated in areas burned by wildfire or destroyed by windstorms or other natural disasters. Paper birch can survive and grow on nearly any soil type but as with most trees, it grows best on nutrient-rich, moist sites when competition is not too severe—either by chance or through manipulation of species composition by the forest manager. When growing in mixture with other species, paper birch tends to stand out because of its white bark. The proportion of paper birch is easily overestimated, so careful measurements are required to estimate the proportion of paper birch before one can make silvicultural recommendations for a particular stand.

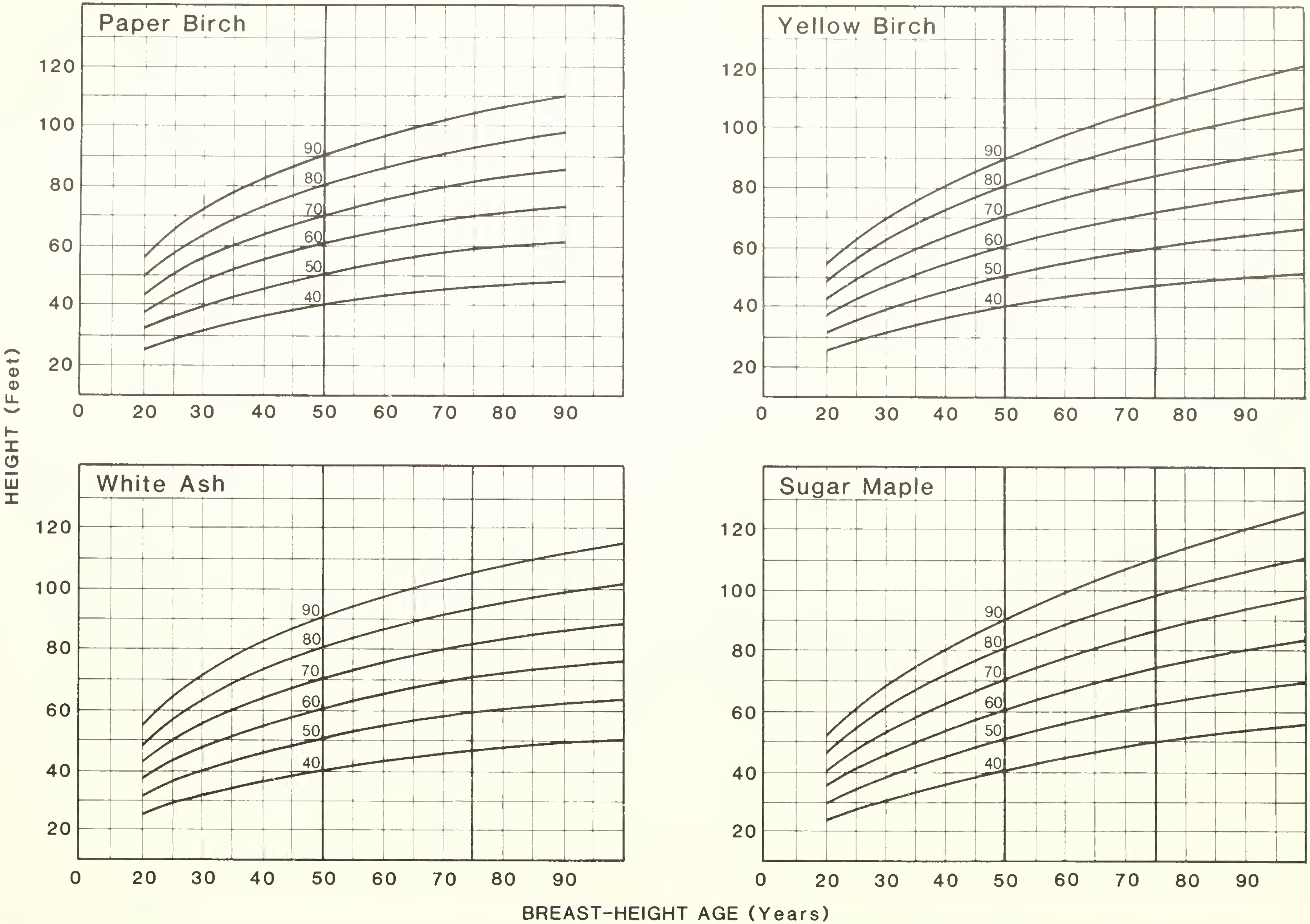
Paper birch is a fairly short-lived species. Sexual maturity and seed bearing occur at about 15 years of age; the greatest quantities of seeds are produced during the 40 to 70 year age period. By the age of 60 to 90 years, paper birch is fully mature and vigor and quality have begun to decline. Dieback of crowns and death of many trees occurs. Some individuals may reach ages over 100 years with a maximum of 140 years. Mountain paper birch (*Betula papyrifera* var. *cordifolia*) lives longer but doesn't attain great size, possibly because of its occurrence at high elevations.

Seed Production and Dissemination

After reaching sexual maturity, paper birch produces some seed nearly every year, a good crop every other year, and a bumper crop 1 year in 10. Seeds ripen in late summer with some dispersal beginning in August and continuing through the winter. Maximum seed fall occurs in September and October before snowfall. Some of the light, winged seeds can be carried great distances by the wind, but the greatest amounts fall within 100 to 200 feet of the parent trees. Paper birch seeds normally germinate in the spring following their dispersal, but recent work indicates that some may be stored in the forest floor for at least 1 year. Majority of seedlings in new stands become established during the first growing season following disturbance, but a small proportion may be added during the second and third years.

Seed Germination

Germination and survival of paper birch seedlings depend greatly on the condition of the seedbed. Mineral soil provides the best moisture and temperature conditions for germination and initial survival. However, nutrient elements are most available from the organic materials in the forest floor. So for establishment and early growth of the seedlings, it is extremely important for the organic material to be preserved in the seedbed. Treatments such as scarification, disking, or light burning help provide the best seedbeds for establishing paper birch.


Paper Birch
Yellow Birch
White Ash
Sugar Maple
90
80
70
60
50
40
HEIGHT (Feet)
BREAST-HEIGHT AGE (Years)
0
20
30
40
50
60
70
80
90
120
100
80
60
40
20

Site Requirements

Paper birch becomes established and grows reasonably well on a wide range of soil-site conditions. Intensive culture should be practiced only on sites that are best suited to its establishment and growth. The poorest sites are extremely wet with poorly drained soils, or extremely dry with shallow to bedrock soils or coarse sands and gravels on glacial outwash deposits. The broad range of sites between these extremes generally are acceptable for paper birch, but some may be less suited than others because of the degree of competition from other species and silvicultural requirements to minimize this competition.

Site index (breast height age 50) (Fig. 1) can be used to estimate the relative productivity for paper birch among sites. Where paper birch is not of sufficient age to estimate site index directly, relative productivity can be estimated from site index of other species in the stand (Fig. 2). The procedure for measuring site index is included in the Appendix. In general, sites with site index of 60 or greater for paper birch are considered satisfactory for intensive culture. Sites with a site index lower than 60 require careful evaluation before large investments of time and money are made. Under some management objectives and resources, intensive culture may be justified. For example, on readily accessible land close to a mill or other market, it might be economically feasible to apply silvicultural procedures that would raise site index from 55 to 60, 65, or higher.

Figure 2.—Relationships among site indexes (base age 50) for four northern hardwoods. To estimate site index of species X from site index of species Y, find known site index on curve for species Y; move vertically up or down to curve of species X; read horizontally across to the left to find estimated site index for species X.

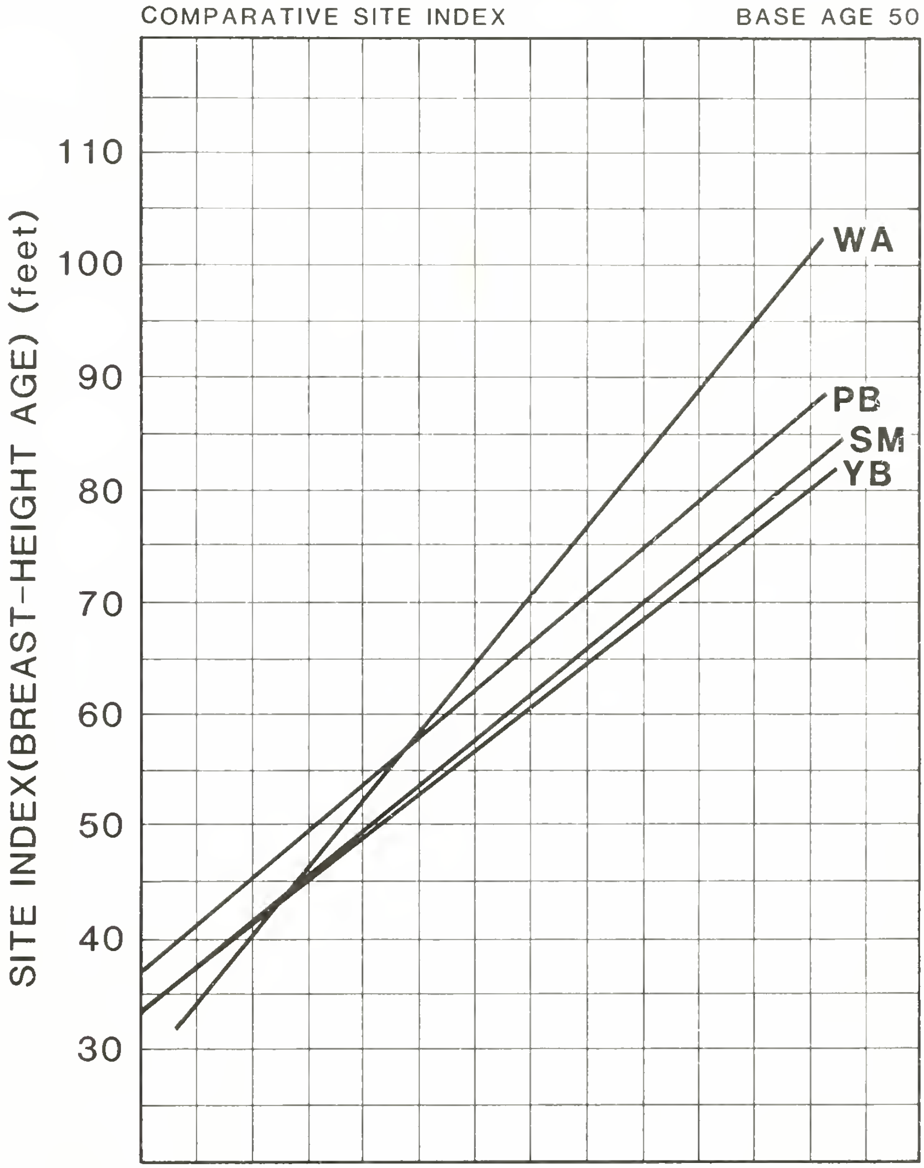


Figure 1.—Site-index curves (breast height age 50) for paper birch, white ash, yellow birch, and sugar maple in Vermont and New Hampshire.

Principal Enemies

Discoloration and decay seriously reduce the quality of paper birch. Branch stubs provide the major avenue of entry for microorganisms that cause these defects. Trees maintained in a vital, fast-growing condition will rapidly close branch stubs resulting from natural branch shedding or wounds made by pruning. It is important to create conditions that confine the discolored and potentially decayed portion of the tree to as small a central core as possible. This is done by encouraging early natural shedding or proper pruning (Fig. 3) while branches are small and the diameter of the bole is 4 inches or less. This will minimize the volume of potentially defective wood and confine it to the interior portion of bolts and veneer logs.

Paper birch is sometimes infected with root pathogens that cause a defect called collar crack. Growth is reduced and foliage may become sparse and pale. Root-damaged trees are easily uprooted by the wind. Stem wounds caused by fire, logging, or falling trees become infected, resulting in a central column of discolored wood that is susceptible to decay. The column of diseased wood equals the size of the tree at the point and time of injury (Fig. 4). Also, stem cankers that ruin trees for timber purposes and make them unsightly for esthetic purposes are often caused by fungi that first infect branch stubs (Fig. 5). Paper birch trees with these conditions will continue to deteriorate, and should be removed from the stand. If the sources of infection cannot be eliminated, some stands may have to be completely regenerated, or converted to other species.

Several insect pests cause various degrees of defoliation of paper birch by eating foliage or mining the interior contents of leaves. Defoliation causes growth rates to decrease during years when it is severe. Dieback in the top or mortality may result if complete defoliation occurs for 2 or more years in succession.

Insects such as the bronze birch borer cause defects in the bole wood by tunneling and mining. These defects decrease the quality of the wood, though healthy trees are seldom killed.

The yellow-bellied sapsucker damages paper birch trees by pecking holes through the bark to the cambial region. This often results in discoloration and ring shake. Severe sapsucker activity can ruin the quality of merchantable-size trees and may result in mortality. Many of the dead portions in the crowns of mature paper birch are the result of sapsucker feeding.

Deer browsing can hinder early height growth of paper birch. This can be particularly serious in areas reproduced by sprouts or planted seedlings. Unless browsed severely enough to result in mortality, the trees eventually grow beyond the reach of deer and stem form recovers. Deer seem to prefer pin cherry as a browse source. Since pin cherry is a common associate of paper birch in regeneration stands, cleaning and weeding operations to remove it should be delayed until the birch has grown beyond the reach of deer (4 to 5 feet in height).

Natural regeneration usually is sufficiently abundant to withstand normal amounts of damage without consequence to the establishment of stands. In areas with marginal quantities of natural regeneration or in birch plantations, clipping of seedlings by snowshoe hare and girdling by mice can be a significant cause of seedling death. Some protection from animals may be required. The forest manager should consult with local wildlife authorities on appropriate control techniques.

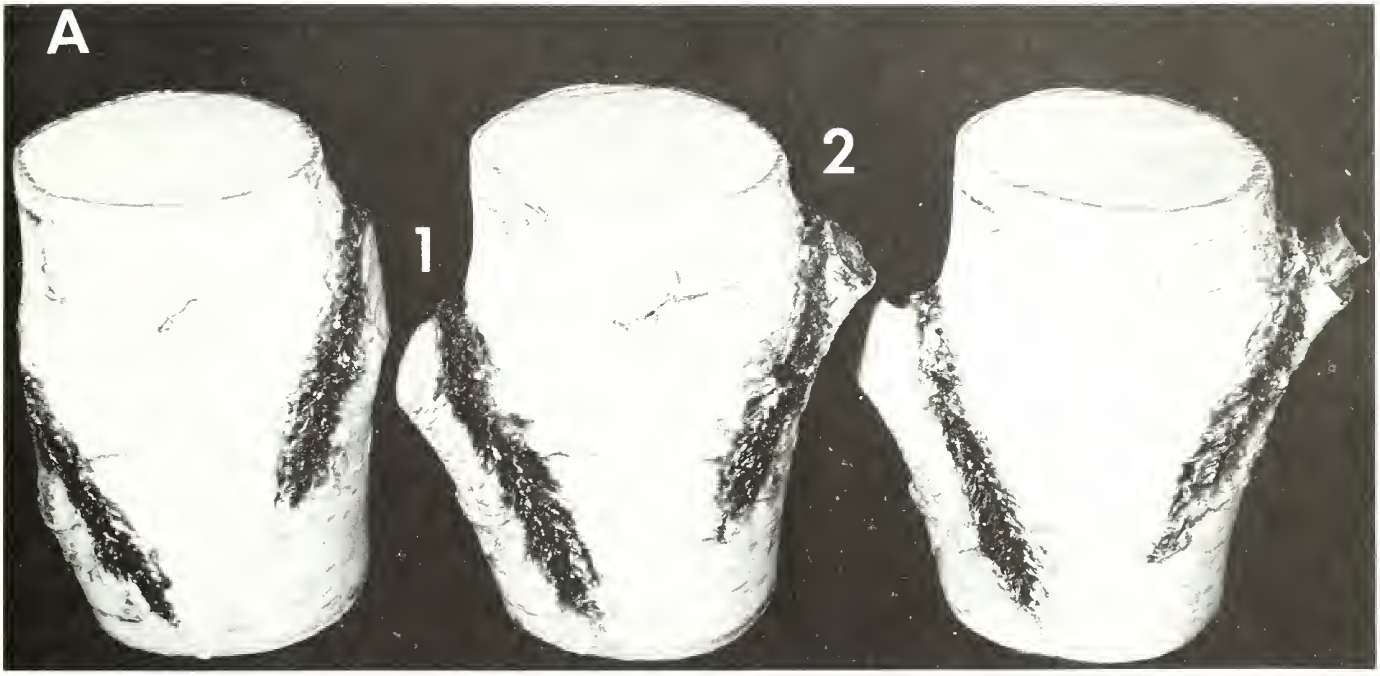


Figure 3.—Guidelines for pruning paper birch: (A) Three views of a stem segment of paper birch showing correct pruning of a live branch (1) and dead branch stub (2). The center segment is correctly pruned. Branches were cut too close on left segment and too long on right segment. (B) Longitudinal section of a paper birch stem and branch showing proper and improper location of pruning cut.

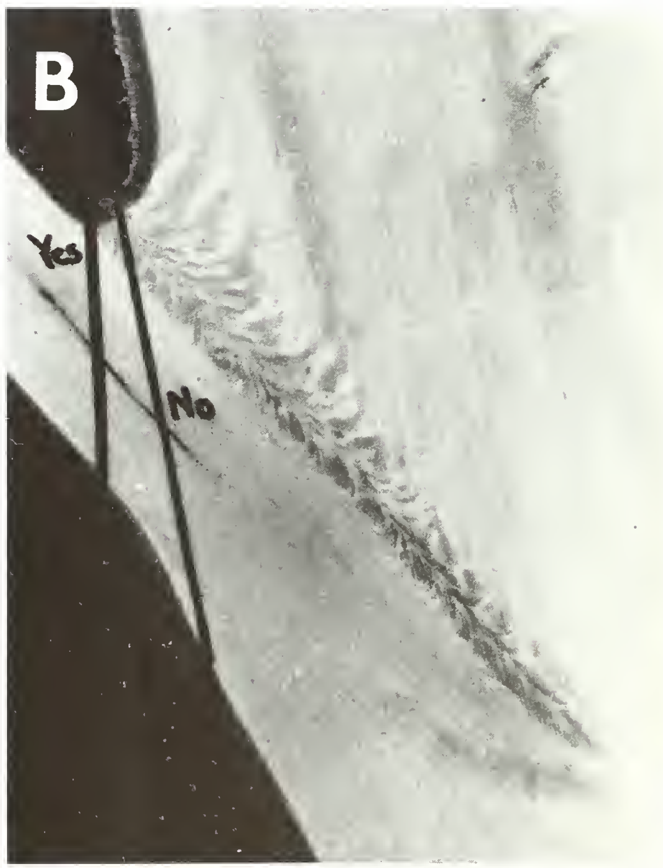
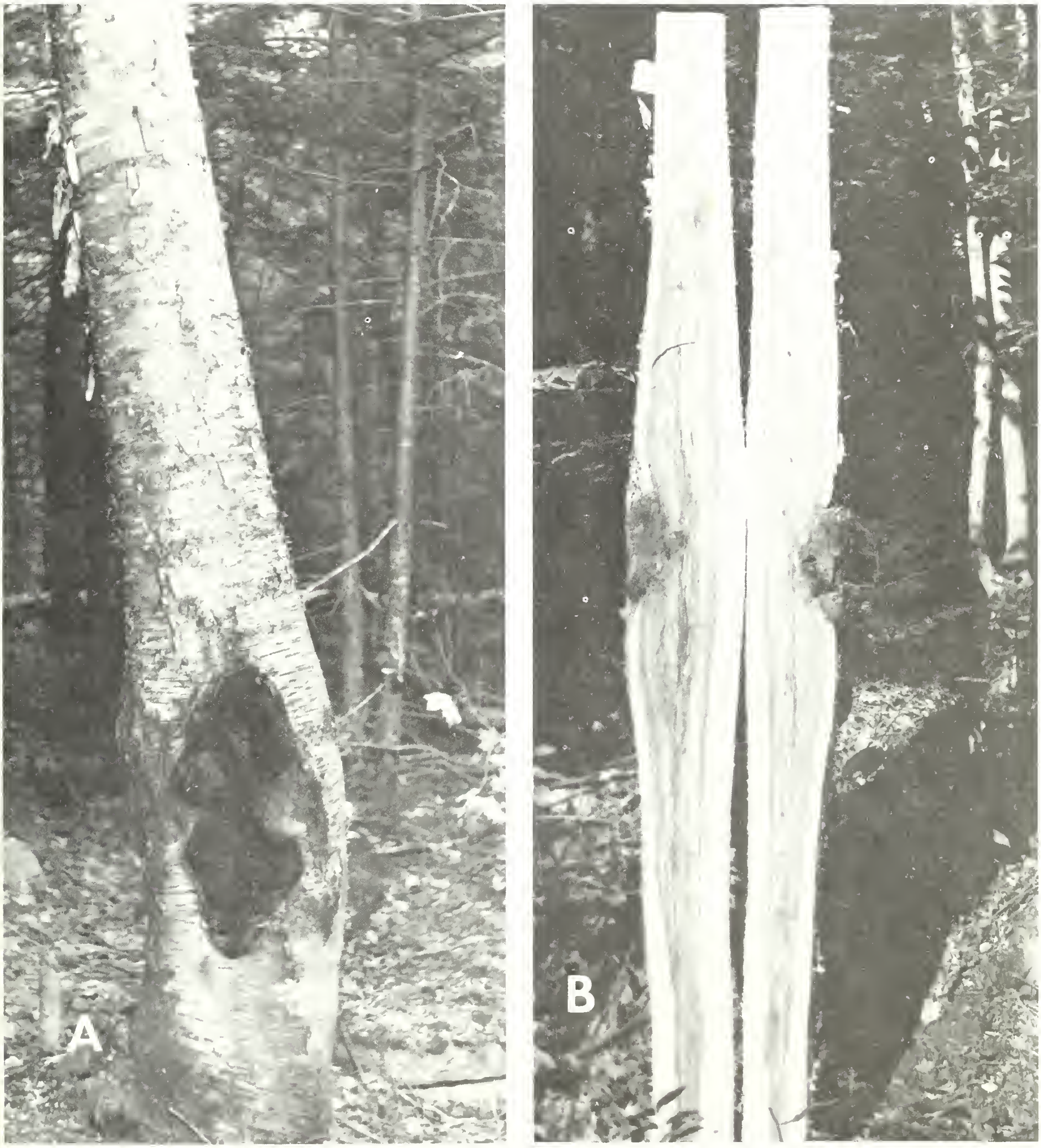


Figure 4.—Dissection of a 100-year-old paper birch tree with a basal wound made by logging or fire 50 years ago. Column of completely decayed wood in the lower stem portion (right) plus the column of discolored wood in the upper stem portion (left) equals the size of the tree at the time of injury.

Figure 5.—(A) Sterile conk of *Poria obliqua* on paper birch. The margin of the hard mass of fungus material usually pushes into the bark around the tree rather than above and below the wound. Swollen stems result from such cankers. (B) Dissection of a paper birch, showing the black sterile growth of *Poria obliqua* on a stem stub and the column of discolored wood associated with it.



Management Objectives

This guide assumes the objective of producing high-quality paper birch as a timber crop. Boltwood, sawlogs, and veneer logs are the primary products sought in the intensive culture of paper birch stands. Products of lower value, such as firewood or pulpwood, may be secondary products, particularly of earlier thinning operations. Some species other than paper birch may be included in the stand, but these too should have potential for high-value products. Any stand without sufficient quality potential for high-value paper birch products should not be managed as a primary paper birch stand. This point should not be lightly taken. If the stand cannot be managed as a paper birch stand, it might qualify for a mixed stand of other hardwood species, or even softwood species. It would be shortsighted to liquidate an immature stand of any species in the pole or small sawtimber stage at a time when those trees are making their greatest growth in value.

In addition to its value as a timber tree, paper birch adds to the beauty of roadsides, campgrounds, and other intensively used outdoor areas. Management of individual trees or small groups of trees for aesthetic purposes is not differentiated in this guide, though the same ecological principles apply.

Levels of Management Intensity

The overall management goals are to improve yields and quality of the growing stands to maximize returns from the final crop. In **intensive** management, the developing stand is molded from a young age to contain sufficient growing stock of the very best possible quality trees to fully occupy the site. The manager selects and releases the growing-stock trees on the basis of species, stem form, and stem size (an indication of relative growth rate), and applies cultural practices such as pruning and protection from injury to minimize defects. Site improvement techniques such as liming and fertilizing also can be applied. Intensive management starts at a young age and continues throughout the rotation by frequent observations of stand conditions and applications of silvicultural treatments as needed.

The available resources, site, or stand conditions often warrant less intensive practices than those described. In these cases, **medium intensity** management can be practiced. Although these treatments might not start as early or be as frequent as intensive practices, their aim is to maximize the numbers and quality of birch stems in the stand. The single most important operation is examining the stand during or before the sapling stage to determine if there will be a sufficient number of quality birches to ensure a satisfactory birch component at maturity. Some stands can develop without early release work; others will require release of the birch or its status in the stand will diminish and management for birch will not be possible. Additional work can be postponed until a marketable product such as fiber, fuelwood, or pulpwood can be harvested to help pay for the treatment.

Low intensity management—or no management at all other than final harvest and regeneration—may be the proper choice on poorer sites. Steep slopes, roughness, and poor soils hinder silvicultural treatment and push costs beyond economic returns. Stands approaching maturity that have not been managed might not benefit from or respond to treatment. Perhaps only one preharvest improvement cutting or thinning to remove least desired species and salvage declining birch would be warranted in these situations. About the only "intensive" management possible in such a situation would be careful planning of the logging operation and marking of trees to minimize damage to the residual stand.

Management Strategy

In addition to the high-value birch product objective already discussed, the management strategy includes two other components: silvicultural requirements of the species and economic considerations. These are integrated to form the management strategies which, in turn, govern the management activities chosen.

Silvicultural treatments concern species composition of the stand and the degree in which paper birch predominates. **Pure stands** are managed with the primary silvicultural treatments directed entirely toward the paper birch component. Although stands as low as C level (Fig. 10) stocking in paper birch can be managed as "pure," a birch component at the B level or higher will give the greatest yields and response to treatment. In these stands, all silvicultural treatments are applied to meet the requirements of the paper birch component. Other species that may be present are given less consideration.

In **mixed stands,** other valuable species are grown along with the paper birch as a component of the stands. Although paper birch still constitutes at least C-level stocking, silvicultural requirements of these other species are considered when treating the stand. Some birch might be removed to favor development of high-quality stems of other species, and the rotation might be carried beyond the age when paper birch would be regenerated in a pure birch stand. In fact, in most cases, the manager would have the option of converting to a longer rotation of the more tolerant, longer-lived species like ash, yellow birch, sugar maple, and beech when the paper birch matures and is harvested.

In **other stands,** less than C-level stocking of paper birch, the birch can be grown in association with lower value products like fuelwood or pulpwood. The fact that paper birch boltwood has high value at smaller sizes allows it to be grown on a short rotation along with species of pulpwood quality. The presence of birch in the stand in proportions as low as 10 to 20 percent of the basal area may effectively increase value per acre and allow some silvicultural treatments to the whole stand that otherwise would not be economical. This situation is of particular value to the small woodlot owner who is growing his own fuelwood or producing even a small volume of high-value material of other species. Paper birch serves as a cash crop analogous to the small plots of tobacco grown on many small farms throughout the South.

Economic considerations fall into two categories: (1) producing raw material for a manufacturing process, or (2) maximizing financial returns from a forest property. In the first case, the landowner also may own a business that requires a particular type and quality of roundwood for its operations—birch boltwood for a dowel or spool manufacturer for example. All forestry operations will be applied to maximize the quantity and quality of this specific product. Thus, the value of the manufacturer's product governs the value of the roundwood and may justify a larger timber management investment than for wood sold on the open market.

In the second case, the economic objective might be to provide sustained even income from the forest property. Paper birch and other species would be treated to maximize growth potential and quality for the entire forest property while sustaining sufficient growing stock for continuous production. Another choice might be to "cash in" on paper birch to maximize current income and at the same time minimize impacts on long-term income. This implies a heavier cutting in the paper birch component than would be recommended in the previous case, and perhaps converting from pure paper birch to a mixed stand with a paper birch component.

In all cases, the role of paper birch is governed by the fact that it is a fast-growing, early-maturing species of high value that can respond to treatment and provide economic returns in a relatively short time.

Site and Stand Evaluation

The first step in establishing management programs is to evaluate site and stand conditions. The manager already may have his objective and goal clearly in mind and wish to determine if a specific stand can be managed to achieve this goal. Or he may use site and stand evaluation techniques to search out suitable stands from among those available to him. Or, as will be most common, the landowner/manager may want to assess the qualities of a specific site/stand situation to determine the most appropriate management options. In any case, the manager needs to obtain information about site and stand conditions—both general and specific—on which to base his decision.

The following sections provide guidelines and techniques for gathering and evaluating site and stand data for these purposes. The information is based on past experience, research data, and general knowledge of site and stand conditions in the Northeast. The use of these guides and recommendations requires a certain amount of judgement and flexibility on the part of the user.

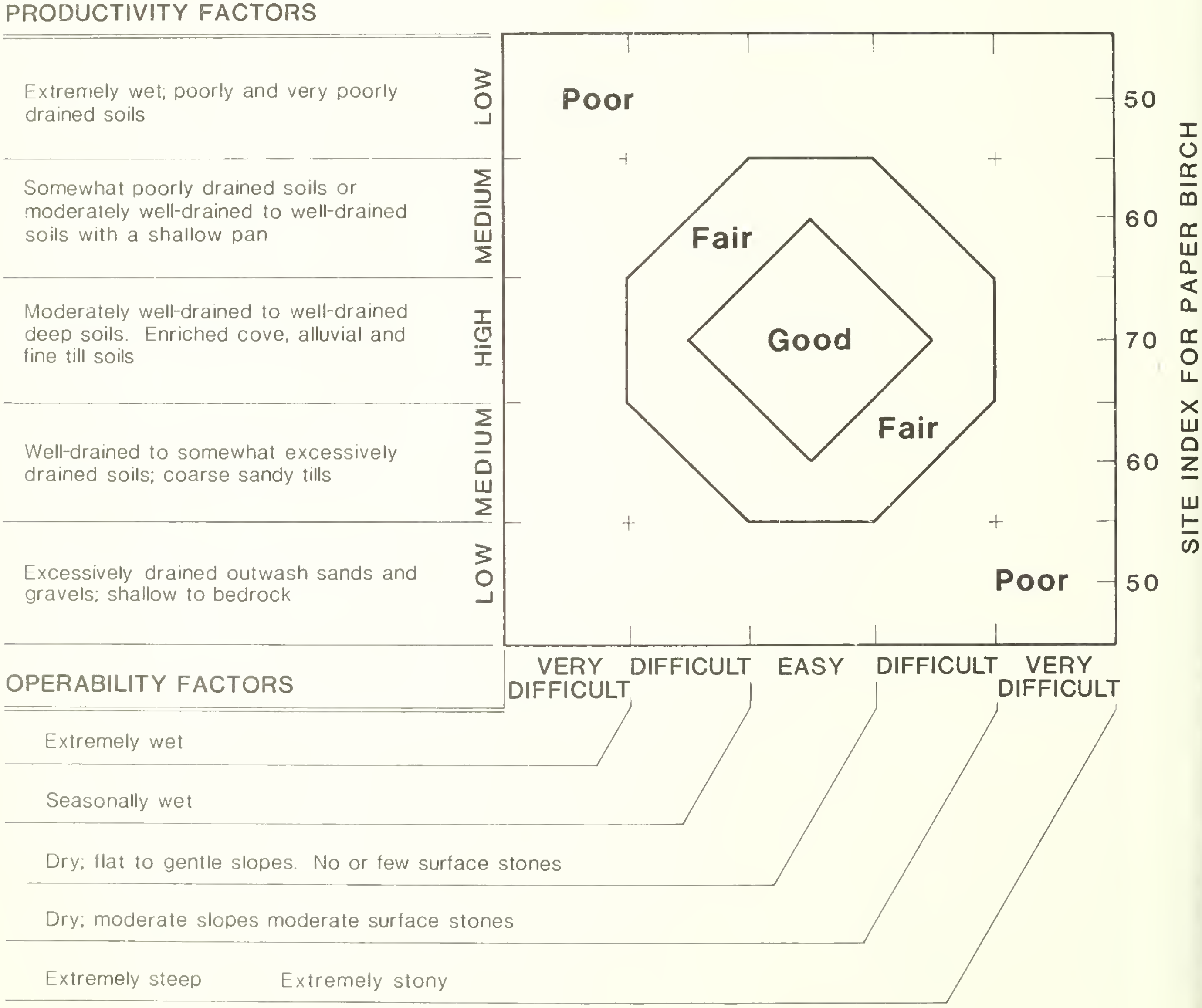
Site Evaluation

The first step in deciding a course of action is to examine the area being considered for treatment. The first look should be a general reconnaissance to determine the stand boundaries, total area involved, and general uniformity of site and vegetation. Site characteristics can be evaluated in two categories: (1) those affecting operability, and (2) those affecting biological productivity of paper birch and other species. The former includes accessibility, proximity to markets, and soil properties—including steepness of slope, degree of stoniness, and wetness—that could hamper silvicultural operations. The biological aspects include the soil, climatic, and other environmental factors that directly affect tree growth.

Guidelines from Figure 6 can be used to rank a particular site in relation to the standards prescribed, and to compare two or more potential sites. The manager's judgement determines how much weight each of the factors carries for his particular situation. Strength in one area may compensate for weakness in another area in some cases, but not in others.

Sites ranked as "good" will have minimum management limitations and the widest choice of options for management practice. Sites ranked with "poor" suitability have one or more strong limitaitons to management practice. This will reduce the management options possible on that site, but some form of management may be possible if the limitation can be overcome. Sites in the "fair" category have some degree of limitation to management, but the chances for overcoming these limitations are greater and the management options available are greater than for those ranked as "poor."

Figure 6.—Site suitability for paper birch management based on productivity and operability factors. Shaded areas are combinations of operability and productivity factors that are not likely to exist, but would rate poor if they did.



Site Index

Site index is the best measure of site productivity currently available. Measurements of site index are required for paper birch or for another species that can be used to predict paper birch. Criteria other than site index should be used to estimate potential productivity of stands that are less than 20 years old. Soil guidelines are provided in Figure 6. When there is a choice among several reproduction stands of equal age (within 2 years), the sites with tallest trees of any species common to all—paper birch, pin cherry, or aspen—would rate relatively higher than the others. Or young stands with trees as tall or taller than those in somewhat older stands probably indicate relatively higher potential productivity.

Again, the owner/manager needs to consider individual practical requirements applicable to his particular situation and management objectives in making the overall assessment of site suitability.

Stand Evaluation

The management stand, or featured stand, dominates the site—or in reproduction stands can be made to dominate through cleaning or weeding—as a continuous cover of dominant and codominant individuals. Species other than paper birch usually become established as understory trees and start to enter the management stand from below toward the end of the rotation. These trees need to be recognized in the overall management picture of older stands, but they do not enter into computation of growing-stock levels when making decisions for thinning and other silvicultural treatments in the main or featured stand.

Stand Diagnosis

The first step in stand evaluation is to measure species composition and stocking level of the stand. The data needed are number of trees and/or square feet of basal area per acre for each species or species group. The proportion of plots with sufficient trees or basal area determines degree and uniformity of stocking.

Reproduction Stands

Reproduction stands have a mean stand diameter of 1 inch or less (0–1.5 inches). They are best evaluated by establishing a number of milacre (6.6 by 6.6 feet square or 3.7-foot radius circular) plots uniformly distributed over the area. At least 20 plots should be measured in stands of 10 acres or less and at least 1 plot per acre in larger areas. Observe and count the potential crop trees of paper birch and other desired species on each plot. Also, observe and count species that are overtopping the birch or threaten to dominate it.

Consider a plot stocked with paper birch if it has at least two vigorous free-to-grow birch seedlings or three vigorous seedlings that need release. Consider the tallest, best-formed paper birch on the plot when making the free-to-grow judgement. Visualize an inverted 90° angled cone with its apex resting on the top of the candidate tree. If the crowns of nearby trees interrupt this cone, the tree needs release. If not, it is free to grow (Fig. 7). Grasses also cause severe competition for paper birch. Consider any birch on plots dominated by grasses as needing release and note this under "Remarks" on the tally form. Paper birch stump sprouts may be present in regeneration stands. A stump with one or more sprouts would qualify a plot as stocked with paper birch, but it should be tallied as needing release even if sprouts are taller than the other vegetation.

Final data will be a summary of percent of plots stocked with (1) free-to-grow paper birch, (2) potential crop paper birch not free to grow, and (3) potential crop trees of other desired species (record species in "Remarks" column); plus percent of plots dominated by aspen, pin cherry, or sprouts of any species (from "Remarks" column). A sample tally sheet is provided in Figure 8.

Sapling Stands

Sapling stands have a mean stand diameter of 2 to 4 inches (1.6 to 4.5 inches). The plot size and tally form for seedling stands can be used. Consider a plot stocked when it has one free-to-grow potential crop tree or two potential crop trees that need release. If more than 20 percent of the plots contain aspen or red maple stump sprouts, release will be required to maintain dominance of paper birch in the stand.

Pole and Sawtimber Stands

Stands with a mean stand diameter of 5 inches and larger (4.6 inches and larger) can be evaluated by variable plot point sampling techniques with a 10-factor prism. All trees in the featured stand—dominants, codominants, and intermediates reaching the main crown canopy—are tallied by diameter class, species, and condition—acceptable (potential crop tree) or unacceptable. Figure 9 is a sample tally form.

This tally sheet can also be used to evaluate the effects of various thinning options and to formulate marking rules. Thinning or partial harvest cuts can be simulated by subtracting trees to be cut from the tally sheet and determining the new stocking level for the residual stand. Make up a new sheet, omitting those trees that you believe should be cut to achieve the desired releases of the birch crop trees. For example, if the stand is approaching maturity with no previous treatment, removing low-quality trees and undesired species might be a good management choice. Go over the original tally form and retally, omitting these trees. This will give the new number of trees, basal area, and mean stand diameter of the post-treatment stand. Then the stocking guide can be used to judge if more or fewer trees should be removed.

Figure 7.—Illustration showing a reproduction stand (mean stand diameter of 1 inch or less) of paper birch needing release. Trees 2, 4, 9, and 13 are potential paper birch crop trees. Only tree 4 is free to grow; the others need release. Trees 3, 6, 8, and 10 are paper birch already badly overtopped and are not potential crop trees. If these were sugar maple, beech, or softwood, they could be considered for release. A minimum cleaning would remove trees 1 (red maple sprout clump), 7, 12, and 14. Trees, 3, 5, 6, 8, 10, and 11 would act as trainers to affect branch shedding from the crop trees. A complete weeding would remove all but the crop trees, and some pruning might be required to maintain stem quality.

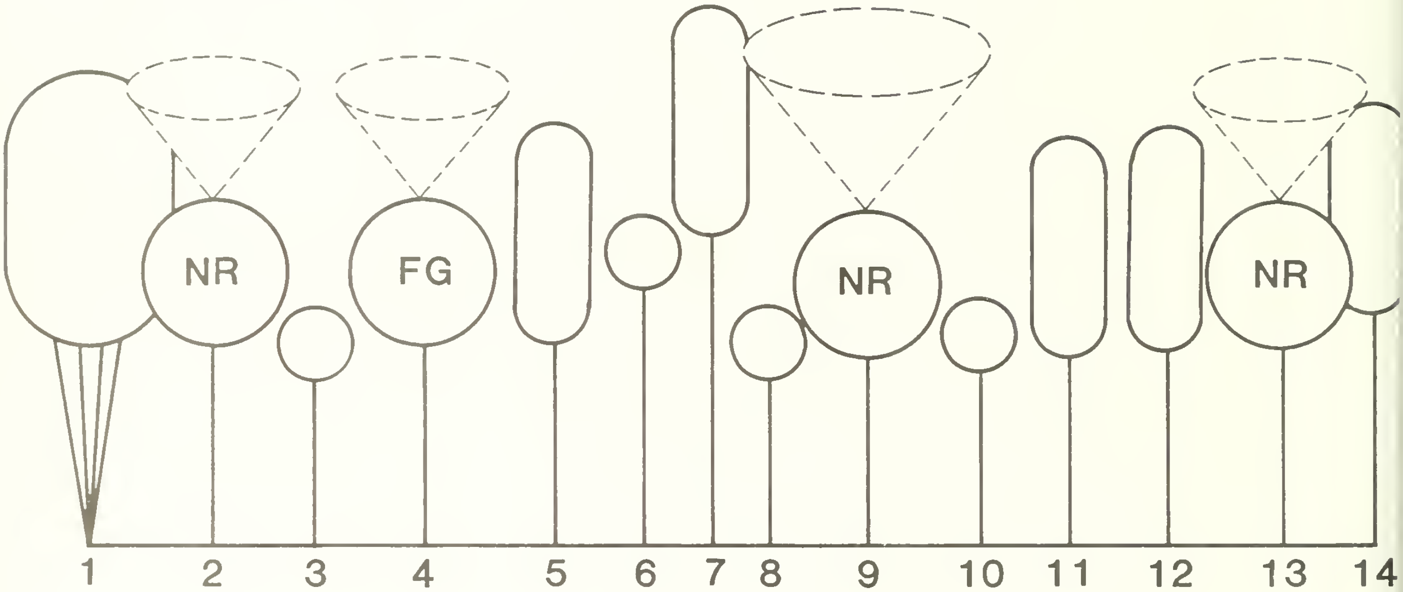


Figure 8.—Sample diagnostic tally sheet for seedling and sapling stands of paper birch.

Plot no.	Paper birch crop trees						Other crop trees						Remarks*
	Free to grow		Need release		Remove trees		Free to grow		Need release		Remove trees		
	No.	Stocked?	No.	Stocked?	X	+	No.	Stocked?	No.	Stocked?	X	+	
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
Total													
% Stocked													
Trees per acre													

Milacre plot = 6.6 by 6.6 feet or 3.7-foot (3 feet 8 inches) radius
% stocking = No. of plots stocked ÷ total plots X 100.
No. of trees per acre = total no. trees ÷ total no. of plots X 1000
X = No. of single stems to remove to release at least two crop trees.
+ = No. of sprout clumps to remove to release at least two crop trees.
* Record species of other crop trees, plots dominated by grass, aspen, pin cherry, or sprout clumps.

Figure 9.—Sample tally form for pole- through sawtimber-size stands.

	Species					Total		
Dbh Class	Paper birch	Other desired hardwood	Undesired hardwood	Desired softwood	Undesired softwood	Desired	Undesired	Remarks
2								
4								
6								
8								
10								
12								
14								
16								
18								
20								
22								
24								
Total								

Number of points tallied: __________

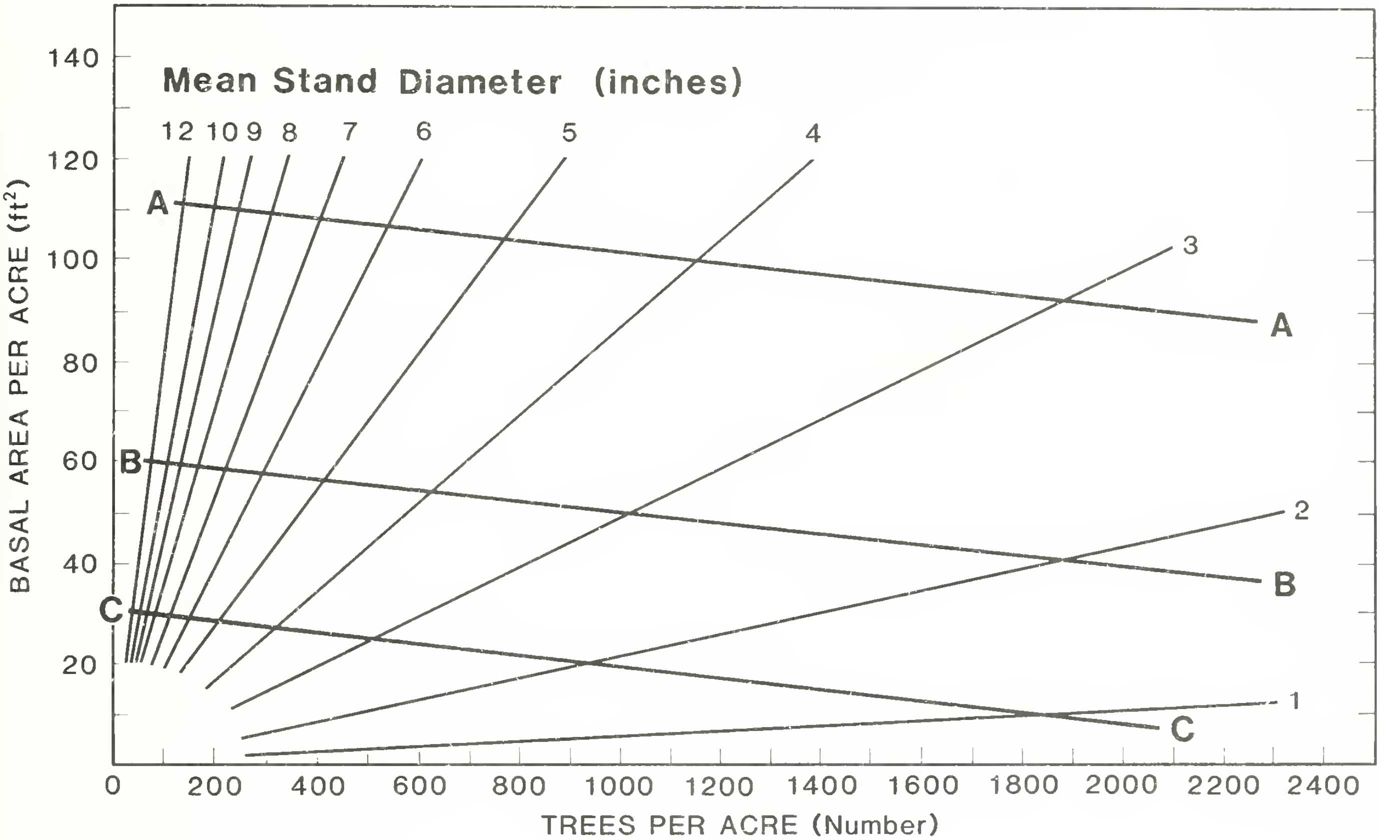
For each species diameter class: Divide number of trees tallied by number of points tallied and look up trees per acre in Appendix II. Basal area per acre equals 10 times number of trees tallied divided by number of points tallied. Obtain appropriate totals by species and diameter class.

SUMMARY	Basal area per acre	No. per acre
Paper birch	______	______
Other desired hardwoods	______	______
Desired softwoods	______	______
Total desired	______	______
Undesired hardwoods	______	______
Undesired softwoods	______	______
Total undesired	______	______

STAND DESCRIPTION	All Desired Species
No. trees per acre	
Basal area per acre	
Mean stand diameter	
Basal area at A level	
Basal area at B level	
Basal area at C level	

STAND PRESCRIPTION

Figure 10.—Stocking guide showing relationship of mean stand diameter to basal area and number of trees per acre for paper birch in the Northeast.



Stocking Guide

Young stands of natural reproduction contain large numbers of small trees per acre. With age, the trees grow larger and competition-induced mortality reduces their numbers. The stocking chart (Fig. 10) shows the relationship between number of trees, tree size (mean stand diameter), and stand density (basal area per acre). The area of the chart marked by the A line and above represents the course of development for fully stocked, natural unmanaged stands. Stands with stocking above the A line are considered overstocked.

Individual trees grow slowly and require a long time to progress to the larger sizes of maturity. These fully stocked stands produce the greatest total quantities of biomass. Increasing the growing space available to individual trees by thinning allows the individual tree to grow faster, but may reduce the total production per acre. The aim of management is to maintain the required number of trees of desired species, form, and quality per unit area to maximize total value production of the desired product.

Stands with stocking level at or above the B line are adequately stocked and can fully occupy the site. Total growth per unit area varies relatively little among stands with basal areas near the B line. The B line represents the stocking level below which competition-induced mortality is minimized.

Depending on the number of quality stems available, thinning treatments can be applied to reduce stocking levels anywhere between the A and B lines. If there are markets for small-size material that would make frequent entries into the stand possible, then each thinning should reduce stocking part way to the B level. For less frequent entries, stocking should be reduced to the B level in one or two treatments.

By their nature as early successional stands, paper birch stands produce light shade. The more tolerant, longer-lived species may become established in the understory and any thinning in the overstory will encourage these invaders. Reducing stocking to the C level or below will allow the invading species to develop to the point that they may interfere with birch growth. Avoid this situation unless the long-term goal is to encourage succession, and convert to tolerant hardwoods, spruce-fir, or pine when the birch is mature.

The C line also can be used to decide whether a stand has enough paper birch to merit treatment as a pure birch stand; that is, if a stand has overstory basal area equal to or greater than C-level stocking in paper birch, it is satisfactorily stocked for management as a birch stand. On the other hand, an open stand that is all or nearly all birch but does not reach C-level stocking probably would not be suited to management.

Regenerating Paper Birch

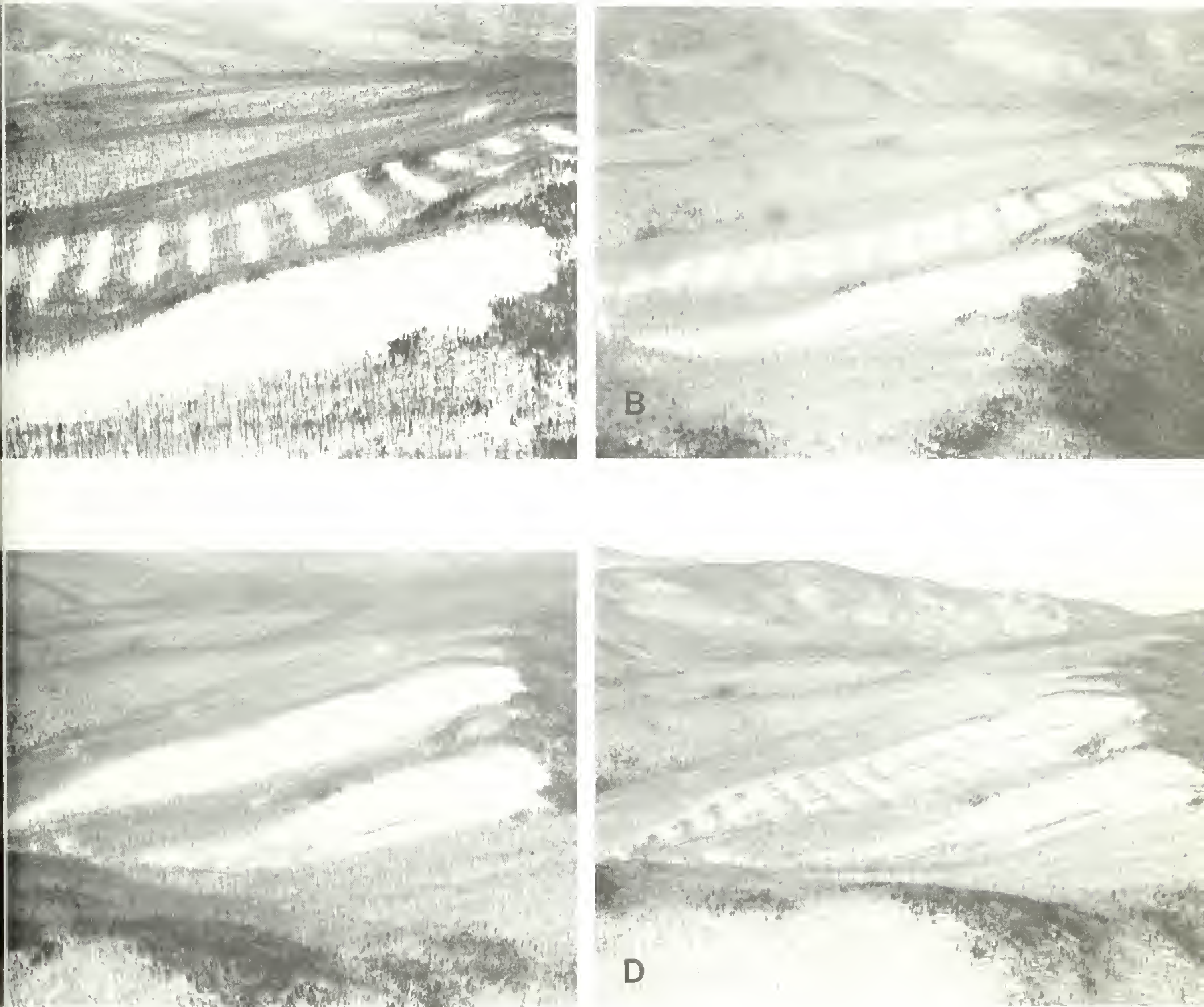
Paper birch requires large openings and full sunlight for successful regeneration. Clearcutting—harvest or removal of all trees larger than 1 inch in diameter—in blocks up to 40 acres in size, in alternate strips, or small patches of about 1 acre can be used to regenerate birch.

Scarification of the soil by breaking up surface organic horizons and mixing with surface mineral soils provides ideal seedbed conditions for germination and establishment of paper birch seedlings. Logging with modern skidders during seasons when there is no snow and the soil is not frozen provides adequate scarification. In full-tree logging, skidding trees with branches attached ideally prepares the site. There is no slash and nearly 100 percent of the area is scarified without loss of the nutrient-rich forest floor material. Adequate quantities of seed may not be dispersed into cuttings wider than 300 feet for cuttings made during the summer season before seed matures on the trees being harvested. Also, in years when a poor seed crop is expected, it would be good insurance to leave three to five well-distributed paper birch trees per acre. They should be healthy, full-crowned trees capable of producing abundant seed. The seed trees can be removed after two seasons with minimum damage to the regeneration.

Where large clearcuttings are undesirable—on steeper slopes, especially on south- and west-facing aspects, small ownerships, or where a mixture of yellow birch and other species is desired—cutting in narrow strips or small patches is recommended. In stripcutting, one-third of the area is cut in 50-foot-wide strips oriented in an east-west direction. After 2 or more years, the second third is cut by removing another 50-foot-wide strip on the south edge of the first cut. The final strip is removed as soon as regeneration is established in the second cut area (Fig. 11). This provides the maximum seed source and also protects the developing regeneration during its establishment. Full sunlight and open conditions favorable to paper birch are established when the final strip is cut. This form of cutting gives maximum protection to the site and minimizes erosion potential and leaching of nutrients to streamflow.

Small patches (less than 1 acre) also can be used like strips. They provide essentially the same conditions, except that new patches are much more difficult to fit in among older ones and to systematically cover the entire area in a particular stand. Such cuttings retain a paper birch component when combined with uneven-aged management. Patches may be used in special circumstances on very small tracts, roadside areas, parks, or other areas where there is insufficient space for strips or where the esthetic appearance of clearcut strips would be undesirable.

Figure 11.—Aerial view of a progressive strip cutting with a large block clearcutting in the foreground: (A) One-third of the area cut in 50-foot wide strips; (B) Second one-third cut 2 years later; (C) Entire area cut after additional 2 years. Note buffer strip of trees along brook in center of cutting; (D) Area 6 years after initial cut. Note that development of regeneration still shows strip pattern. Block clearcut in foreground also is regenerating well.



Shelterwood cuttings might also be used where strips or patches are undesirable or impractical, though few research data are available from the Northeast. The first cut should remove 60 percent of the total basal area. The residual stand should maintain at least four to five paper birch seed trees per acre. All trees down to 1 inch dbh should be removed at this time. After a 2-year establishment period, the second cut should remove the remaining overstory. Waiting longer than 2 years for the final cut may result in decadence and loss of value by the residual paper birch trees. Also, the proportion of more tolerant species will be increased.

If the harvested stand contained abundant red maple, beech, or aspen, stump sprouts and rootsuckers will be abundant. Mechanical removal or herbicide treatment will be necessary to prevent domination of the birch seedlings. This treatment might consist of a preharvest stem injection of unwanted species, treatment of freshly cut stumps during the harvest operation, or treatment of young sprouts when the residual trees are removed from the area after the harvest has been completed. A repeat treatment may be necessary within a few years in areas where the undesired species were initially abundant.

Birch stump sprouts can be left to supplement the seedling regeneration. Where there was a high proportion of paper birch, especially if the stand has been previously managed, stump sprouts can provide a quick source of reproduction. Sprouts can be especially important in the small stands and sensitive areas mentioned previously.

Any clearcutting requires precautions to avoid soil erosion and water contamination. Problems can be avoided by proper design, layout, and construction of roads. Careful stream crossings, water bars on skid trails, and seeding of temporary roads and skid trails following cutting should be used. A partially cut (50 percent or less of stand volume) buffer strip should be left along all streams and other significant water courses.

Seeding and Planting

Where paper birch seed source is completely lacking, or where genetically selected parentage is desired, birch seed or seedlings may be planted directly on prepared seedbeds. In direct seeding, best results are obtained by sowing seed at the rate of one million viable seeds per acre on well-prepared mineral soil seed spots 3 to 4 feet in diameter, or on 3- to 4-foot-wide strips, uniformly spaced over the clearcut area. Adding a slow-release fertilizer to the seed spot will stimulate early growth of the seedlings.

Either container-grown or bare-root seedlings also can be planted. Scarification to disturb the surface organic horizons in recent cuttings, and cultivation or herbicide treatment of sodded fields are necessary for satisfactory survival. A herbicide treatment to control competing vegetation for the first 2 to 3 years following planting would be ideal. But, with initial site preparation and 6- by 6-foot spacing, satisfactory stand establishment should be obtained on most sites. Once established, the same intermediate cultural practices will be required for plantations and direct-seeded areas as with natural regeneration (see section on cleaning and weeding).

Intermediate Treatments

Once regeneration is established, the manager has the opportunity to mold stand composition and stocking level to ensure the highest proportion of birch and other desired species of the highest quality stems throughout the life of the stand. Treatments begin with cleaning or weeding in seedling and sapling stands, continue with thinnings in the pole and small sawtimber stands, and are completed with the final harvest clearcutting or conversion to management for the tolerant, longer lived species. These treatments reduce competition and increase growing space of selected crop trees, i.e., trees that have potential for providing the final product objective.

Selecting Crop Trees

Paper birch has top priority for selection as a crop tree at all stages. In areas within the stand where paper birch is absent, yellow birch, white ash, sugar maple, or red oak can be selected as second-priority hardwoods depending on local markets. If softwoods are present, red spruce, white spruce, or white pine can be chosen. Third priority would be beech, red maple, and balsam fir. Select at the rate of at least two birch crop trees for each one of other species.

Stem quality is the second criterion for selecting a crop tree. In seedling and sapling stands, relative stem diameter is the best criterion for selecting paper birch crop trees. Select trees with diameters at least equal to mean stand diameter. The larger the diameter in relation to the mean, the better the chances of continued superior growth. A few somewhat smaller individuals of the more tolerant species can be selected if they are otherwise vigorous and full-crowned.

In pole stands and larger, select dominant or codominant full-crowned paper birch crop trees. A few crop trees of more tolerant species can be chosen from the intermediate category, but only if they have full crowns for their positions. The stem should be straight and free of forks and excessive branches for a minimum of 17 feet. There should be no logging wounds or injuries caused by insects or wildlife that will degrade the quality of wood within the merchantable stem. Nor should there be insect or disease damage within the crown that will reduce the growth rate. Avoid unstable trees standing on stumps or rocks.

Cleaning and Weeding

Cleaning removes trees or sprouts that overtop or threaten to overtop the desired crop trees from stands not past the sapling stage. Weeding removes all competing vegetation from the stand whether it is overtopping the crop trees or not. These treatments ensure survival and a dominant position for paper birch. They provide maximum stocking of the highest quality stems, and control spacing and distribution of stems. Cleaning should be done at the earliest possible age before desirable stems are physiologically suppressed and while there is a maximum number of individuals to choose from. The smaller stems are easier to treat.

Cleaning and weeding are done by cutting or treating the trees to be removed with an appropriate herbicide. Since herbicides currently available are nonselective, extra caution is required during application to avoid injury to the released trees. The newer brush cutting saws are safe and efficient and are probably best for treating large areas. Some crews prefer light-weight chainsaws in sapling and larger stands. Care is required in felling trees of this size to avoid bending over the released birch trees because they are quite limber and susceptible to being buried by the tops of felled trees. Resprouting will be minimal if an appropriate herbicide treatment follows cutting. Cut stems can be treated with a brush, mop, or squirt bottle. In some cases, directed sprays might be used. New and more effective chemicals are receiving Federal labels for use in forestry. The forest manager should consult with a specialist in herbicide treatments to obtain the most up-to-date methods and chemicals available. See Caution on page 28.

The degree of release depends on the manager's objective and the species composition of the stand. If the stand is 80 percent or more stocked with birch with only a few overtopping pin cherry or stump sprouts, selection and release of as few as 100 to 150 crop trees per acre may be sufficient. But if there is a strong aspen or red maple sprout component, complete removal is recommended to establish birch as the dominant species. If red maple stump sprouts are few (10 to 20 per acre), thin some to one or two stems per clump and leave in the stand; if many, remove all and treat the stump with herbicide to keep from resprouting. Otherwise, red maple will be a dominant component of the future stand with little potential for other than fuelwood or pulpwood. Any paper birch stump sprouts that are to remain as part of the stand also should be thinned to one or two of the best stems to maximize growth rate. The most intensive treatment would be complete weeding to leave a uniformly spaced plantation-like stand of pure birch or birch plus other species (Fig. 12). This kind of treatment requires the greatest investment in time and expense but should provide the largest quantities of high-quality paper birch.

Thinning

Thinning removes trees competing with desired crop trees from stands beginning with the late sapling—early pole class up to the sawtimber class prior to final harvest cut. Thinnings remove trees of poor quality and undesired species from stands not previously cleaned or weeded, and reduce stocking to desirable levels indicated by the stocking guide. Early thinnings may be similar to cleaning in that they remove aspen, pin cherry, or red maple sprouts that are threatening to dominate birch crop trees. Any poorer quality stems and lower crown class-individuals of birch or other potential crop species also may be removed in early thinnings. Since this material is small, it is generally not marketed, but potential fiber or fuelwood sales might return at least part of the treatment cost. About 300 to 400 crop trees per acre should be identified and released at about 20 to 25 years of age (Fig. 13). As many as half of these may be other than paper birch if management for a combination of species is desired. Final stocking level should be close to the B line on the stocking guide. In previously untreated stands, two treatments about 5 years apart may be required to reach this level without opening the stand too rapidly.

Figure 12.—A 13-year-old stand of paper and yellow birch that was cleaned and weeded at age 7. About 900 trees per acre remain. Note the dense stocking of pin cherry in untreated stand in background.

Figure 13.—A 47-year-old stand of paper birch with tolerant northern hardwoods in the understory. The stand was thinned once at age 25, releasing 300 to 400 crop trees per acre. Growth differential between control and treated persisted for more than 16 years.

Later thinnings can begin in about 10 years after many of the trees are large enough to be harvested for firewood or pulpwood. Use the stocking guide to determine the level of residual stand required for adequate stocking and remove sufficient numbers of trees to reach this level. First, remove any trees that have been injured or have become diseased since initial selection; any remaining noncrop trees should be removed next. Final removals should be from among other crop trees to provide uniform distribution and free growth of the very best remaining trees that will be carried to the final harvest. Two or three light thinnings spaced far enough apart for a profitable logging operation will give closer control over stand development than a single heavier thinning.

It is not always possible to predict how a given tree will develop, especially at the early stages of stand development. By selecting as many potential crop trees as possible and by making frequent observations, the selection can be narrowed so that the best trees are always favored and early selections that fail to meet expectations can be removed. A generalized treatment schedule for low, moderate, and intensive levels of management is suggested in Table 1.

Table 1.—Generalized treatment schedule for three intensities of management for high-quality paper birch at various stand ages, site index 60

Treatment	Management intensity		
	Low	Moderate	High
Clean/weed	—	5–10	5
Fertilize	—	—	7
Thin	—	—	10
Fertilize	—	—	12
Thin	—	—	17
Fertilize	—	—	19
Thin, prune	—	20–25	24
Fertilize	—	—	26
Thin	—	—	31
Fertilize	—	—	33
Thin	35–40	30–35	38
Fertilize	—	32–37	40
Clearcut for paper birch boltwood or thin	60	40–45	
	—		
Fertilize	—	42–47	—
Thin	—	50–55	—
Clear cut sawlogs and veneer or remove paper birch and convert to tolerant species (encourage succession)	80	60	45

Fertilization

Paper birch is a nutrient-sensitive species that responds to increased levels of fertility. Research has shown that on many of the medium- to coarse-textured glacial soils of the Northeast, deficiencies of nitrogen and phosphorus commonly limit growth. Adding these nutrients may substantially increase both diameter and height growth of birch and other species in the stand.

Only stands that have received previous cleaning or thinnings should be fertilized. Treated stands should be fertilized 1 or 2 years after a cleaning or thinning so that unwanted trees will not increase their competition with the desired birch crop trees. Response to an application of fertilizer lasts 5 to 7 years, so repeated applications each time the stand is thinned will give the greatest response. If only one fertilizer treatment is planned, make it after the last thinning when trees are larger and putting on their highest value (Table 1).

Recommended fertilizer rates are at least 200 and preferably 300 lb/acre of nitrogen from either urea or ammonium nitriate, plus 100 lb/acre of phosphorus from triple super phosphate. They can be broadcast on the soil surface simultaneously in late fall before the ground is frozen or snow covered or in early spring after snowmelt and before leafout.

Pruning

Paper birch usually sheds its branches without need for pruning. However, in more open stand conditions caused by frequent thinning, some pruning may be desirable. Yellow birch and sugar maple retain branches longer and a few trees of each species may be pruned. Prune only fast-growing trees that have potential for sawlog or veneer-log quality. Potential forks can be eliminated and branches removed to convert otherwise desirable trees into good crop trees. Prune close to but do not remove the branch collar at the base of the limb (use Figure 3 as a guide for proper pruning). Be careful not to injure the stem near the pruning site.

Growth, Yield, and Harvest

Estimates of volume yields under various levels of management and site index greater than 60 are given in Table 2. These yields are for pure paper birch stands. If other species make up more than 50 percent of the stocking, yields will be lower; if less than 50 percent, yields can be higher. Also, material removed in thinning will add to the total production over the rotation. Since we have no experience with intensive thinning schedules over an entire rotation, these figures are only estimates. However, projection of current growth rates indicates that these or greater yields can be achieved.

The final harvest removes all paper birch crop trees. This is either a form of clearcutting and regeneration as described earlier, or conversion to the more tolerant, longer lived species in a continuation of natural succession. In the latter case, the harvest of the birch is a release cutting for sugar maple, beech, yellow birch, or softwoods; future management would follow guidelines in silvicultural guides by Leak et al. 1969, Frank and Bjorkbom 1973, or Lancaster and Leak 1978. In the former case, a new rotation of birch is established and the process begins again.

Table 2.—Minimum yields of paper birch for different management levels on sites greater than site index 60

Stand age	Management intensity		
	Low	Medium	High
years		*cubic feet/acre*	
20	900	900	1,390
25	1,145	1,380	1,870
30	1,380	1,870	2,480
35	1,630	2,215	3,170
40	1,870	2,480	3,830
45	2,175	3,170	4,240
50	2,480	3,550	—
55	2,865	3,830	—
60	3,170	4,240	—
65	3,500	—	—
70	3,830	—	—
75	4,035	—	—
80	4,240	—	—

Flow Charts for Silvicultural Decisions

To determine if reproduction stands require cleaning or weeding treatments to maximize survival and growth of the paper birch component, use the flow chart for reproduction stands 5 to 10 years old (Fig. 14) to select an appropriate prescription. It is important to make this diagnosis and treatment application as early as possible before the birch is suppressed and while stems are small and easy to remove.

The same flow chart technique helps decision making in pole, sapling and sawtimber stands. Keys to prescriptions for thinning and cleaning in sapling and pole stands are given in Figures 15 and 16. Suggestions for harvest/regeneration cuts are diagrammed in Figure 17.

Prescriptions

The following prescriptions were developed for maximizing yields of high-quality paper birch timber products. The manager should rely on his own judgement and experience to determine how closely a specific recommendation should be followed in light of the unique economic and silvicultural circumstances of each forest property. (See appropriate sections of the text for additional details.)

A. Allow to develop to the sapling stage without treatment.

B. Clean or weed to release paper birch and other crop trees of desired species. Manage as a mixed stand using the appropriate silvicultural guide for other species while keeping paper birch free to grow.

C. Mechanically thin by removing one-half of the stems in strips 5 to 6 feet wide, leaving 5- to 6-foot-wide strips. Within the leave strips, remove all aspen and red maple and red oak stump sprouts and other overtopping vegetation.

D. Clean by removing aspen, red maple, or red oak stump sprouts.

E. Clean and thin to release 500 paper birch crop trees per acre, or 250 paper birch and 250 other desired species per acre.

F. Manage for other species using the appropriate silvicultural guide.

G. Do nothing at this stage. Reexamine in 10 years or at age 40. Boltwood is the only product objective for paper birch that is feasible on these sites. Consider prescription B.

H. Thin once to B level. Allow to progress to pole stage. For intensive management, consider fertilization 1 to 2 years after thinning.

Figure 14.—Flow chart of silvicultural options in reproduction stands 5 to 10 years old, mean stand diameter of 1.5 inches or less.

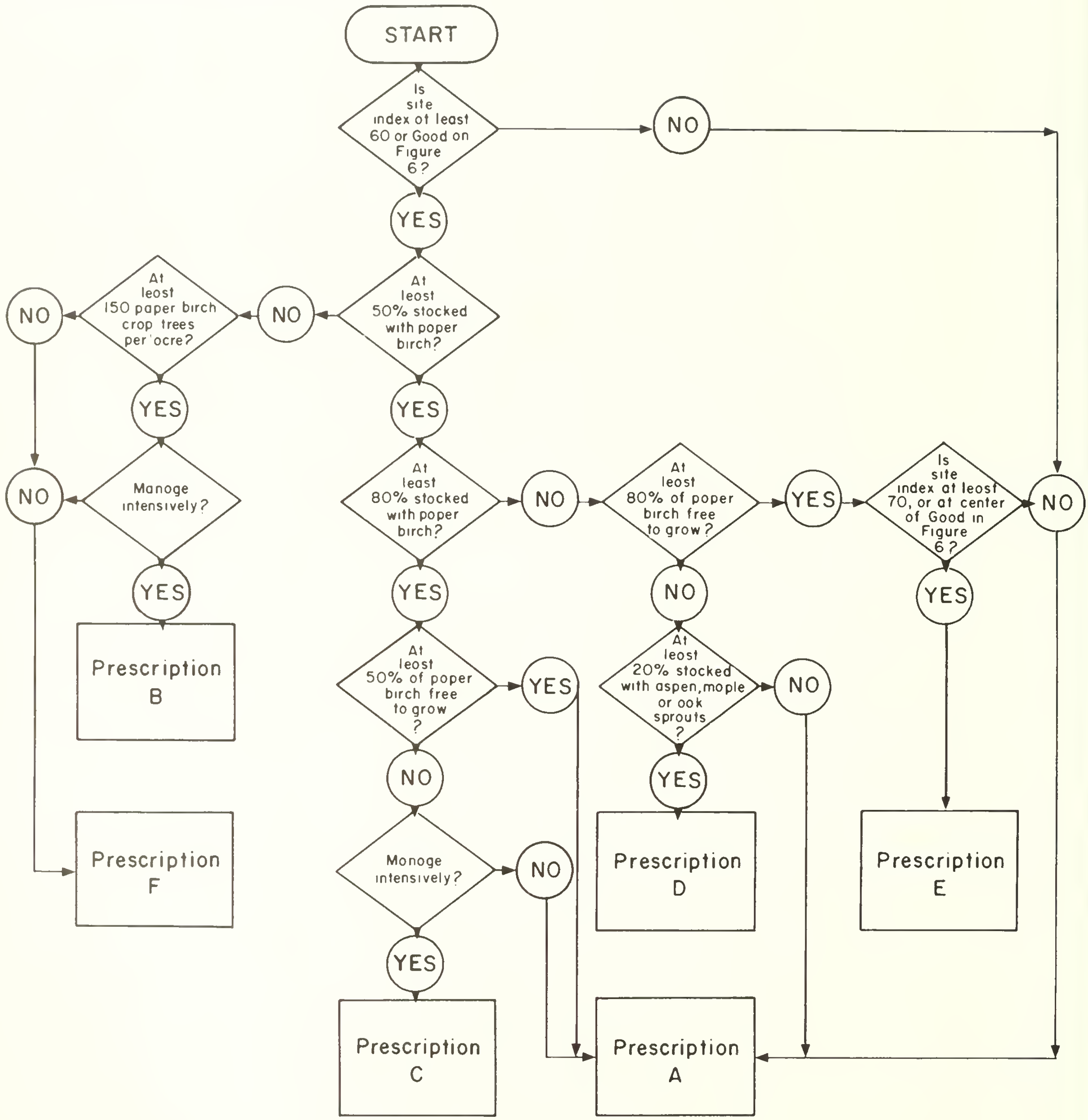


Figure 15.—Flow chart of silvicultural options in sapling stands, mean stand diameter of 1.6 to 4.5 inches.

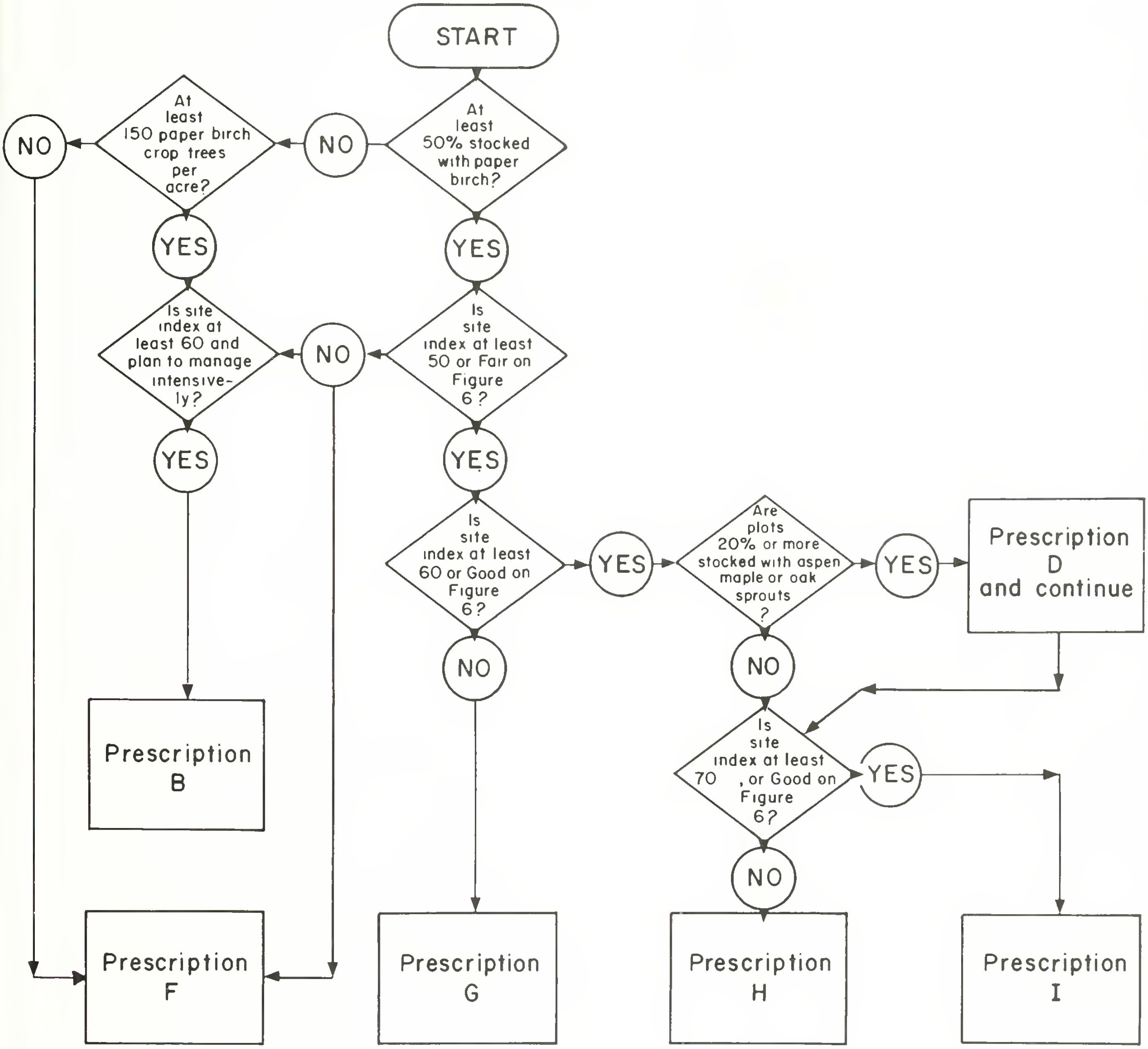


Figure 16.—Flow chart of silvicultural options in pole stands, mean stand diameter of 4.6 to 10.5 inches.

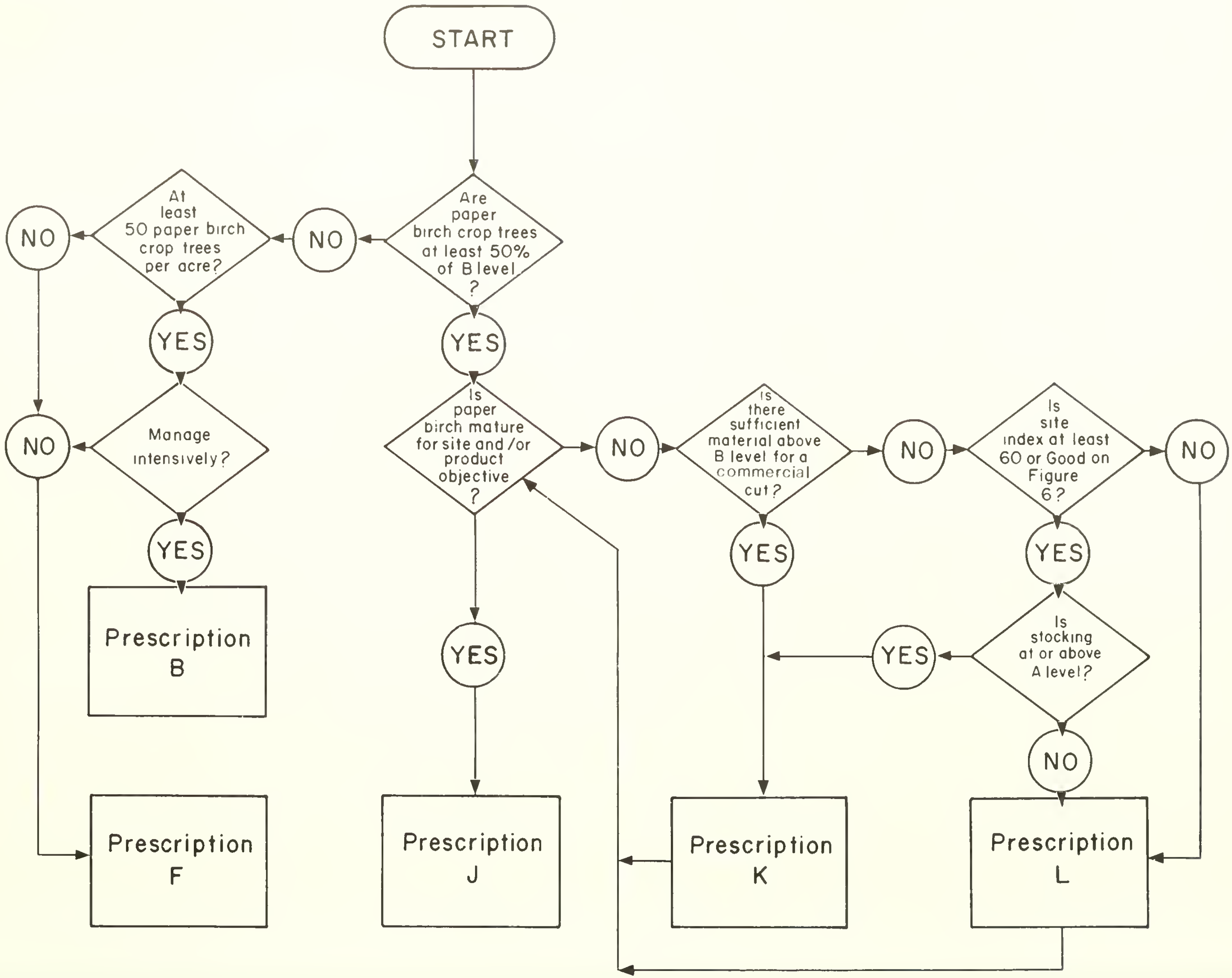
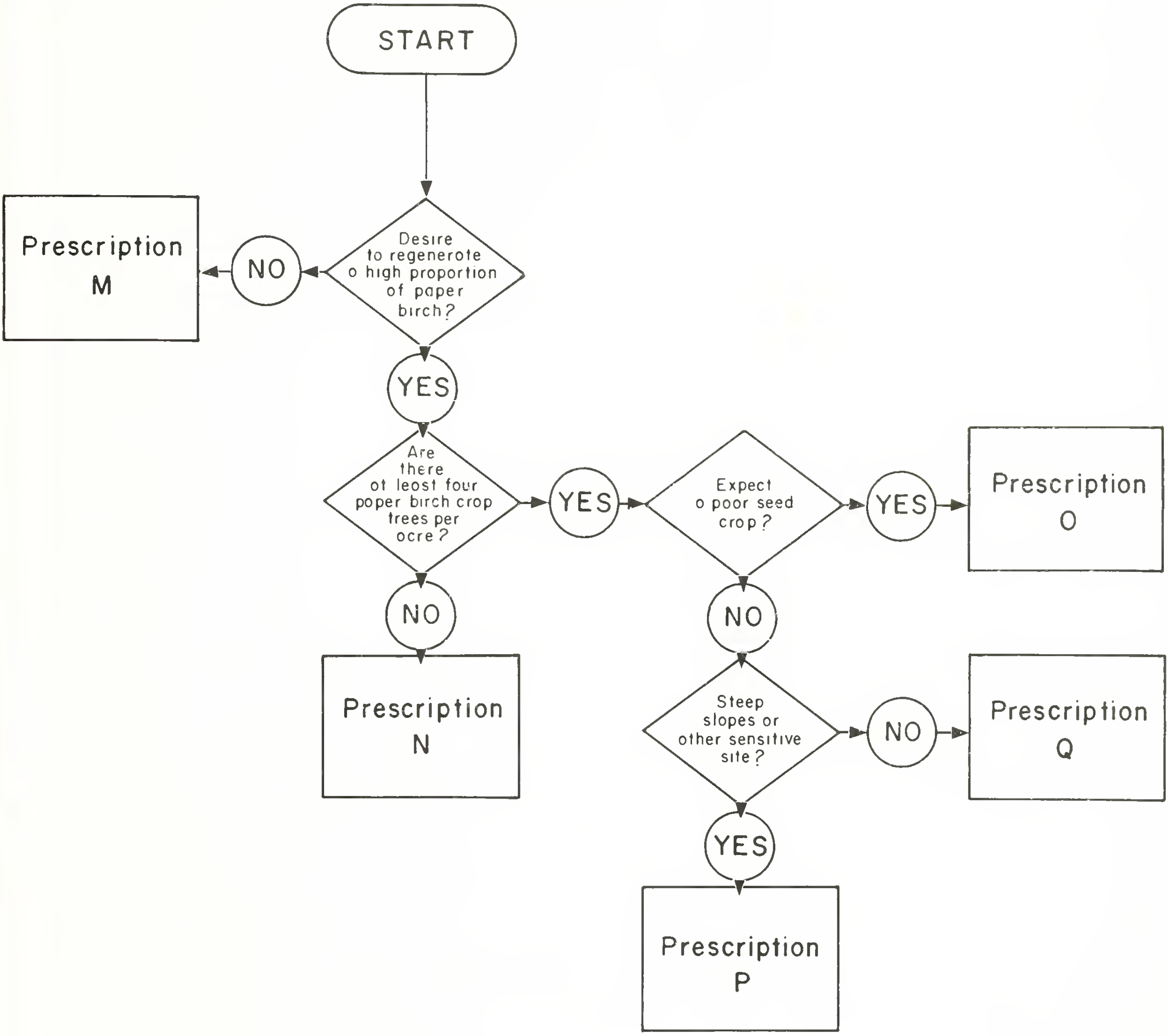


Figure 17.—Flow chart of silvicultural options in sawtimber stands, mean stand diameter of 10.6 inches or greater.



I. Thin to B level now and at intervals of 7 to 10 years until stand reaches pole stage. Subsequent thinnings should produce marketable material. Consider fertilization 1 to 2 years after each thinning.

J. Harvest. Go to sawtimber flow chart (Fig. 17).

K. Thin to B level, releasing enough paper birch crop trees to make B-level stocking in crop trees alone in about 10 years. Consider fertilization.

L. Do nothing now. Reexamine in about 10 years. Consider prescription G.

M. Harvest paper birch and other merchantable products. Manage for other species using the appropriate silvicultural guide.

N. Clearcut in a block up to 40 acres in size and direct seed or plant seedlings to obtain desired stocking of paper birch.

O. Postpone harvest until a better seed crop is expected, or clearcut by the progressive strip method. Consider direct seeding.

P. Clearcut by the progressive strip or small patch method.

Q. Clearcut in a block. If more than 20 acres and cut is in summer, leave 3 to 4 paper birch seed trees per acre.

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Acknowledgments

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Caution

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 as 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 landfill dump, or crush or 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 Environmental Protection Agency, consult your local forest pathologist, county agricultural agent, or State Extension specialist to be sure the intended use is still registered.

Appendix I

Measuring Site Index

1. Select five or more dominant paper birch or other species to which curves apply. These trees should be among the tallest trees in the stand, straight, and free from injury and disease.
2. Measure height from two directions at approximately right angles.
3. Bore at breast height and count rings for age. Sugar maple and white ash are easier to count than the birches. If ash is used, be sure it is not of sprout origin.
4. Using height and age data, read site index from appropriate set of curves. If sugar maple, ash, or yellow birch was measured, convert to paper birch site index using Figure 2.
5. Determine the values of five or more trees to obtain average site index for the stand.

Appendix II

Number of trees per acre by diameter class and number of trees tallied for a 10-factor prism.

Number of trees tallied	Diameter class (inches)												
	2	4	6	8	10	12	14	16	18	20	22	24	26
1	458	115	51	29	18	13	9	7	6	5	4	3	3
2	917	229	102	57	37	25	19	14	11	9	8	6	5
3	1375	344	153	86	55	38	28	21	17	14	11	10	8
4	1834	458	204	115	73	51	37	29	23	18	15	13	11
5	2292	573	255	143	92	64	47	36	28	23	19	16	13
6	2750	688	306	172	110	76	56	43	34	27	23	19	16
7	3209	802	357	201	128	89	65	50	40	32	26	23	19
8	3667	917	407	229	147	102	75	57	45	36	30	26	21
9	4125	1031	458	258	165	115	84	64	51	41	34	29	24
10	4584	1146	509	287	183	127	93	71	57	46	38	32	27
11	5042	1260	560	315	202	140	103	78	62	50	42	35	29
12	5501	1375	611	344	220	153	112	86	68	55	45	39	32
13	5959	1490	662	373	238	165	121	93	74	59	49	42	35
14	6417	1604	713	401	257	178	131	100	79	64	53	45	37
15	6875	1719	764	430	275	191	140	107	85	68	57	48	40
16	7333	1834	815	459	293	204	149	114	91	73	60	52	43
17	7792	1948	866	487	312	216	159	121	96	77	64	55	45
18	8250	2063	917	516	330	229	168	128	102	82	68	58	48
19	8707	2177	968	545	348	242	177	136	108	87	72	61	51
20	9167	2292	1019	573	367	255	187	143	113	91	76	64	53

Safford, L.O. **Silvicultural guide for paper birch in the Northeast (revised).** Res. Pap. NE-535. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 29 p.

This revised guide provides practical information on silvicultural treatments to grow paper birch as a timber crop. It covers treatments for existing stands, the regeneration of new stands, and subsequent culture to maturity. The stocking chart has been revised to reflect results of current growth studies.

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