STOCKING, GROWTH, AND YIELD OF BIRCH STANDS

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INTENSIVE FOREST MANAGEMENT depends heavily upon our ability to measure, control, and predict the growth, yield, or general development of timber stands, regardless of whether the management goal is for timber, aesthetics, recreation, water, or wildlife.

A large amount of mensurational data about birch stands has been developed in recent years or synthesized from available information *(Marquis et al. 1969, Leak et al. 1969)*. This information, which is summarized in this paper, covers site estimation, stocking, short-term growth, and yield. The information about paper birch applies to even-aged stands—in some cases to essentially pure stands that contain 50 percent or more paper birch. The data on yellow birch cover both even-aged and uneven-aged mixed northern hardwood stands with at least 5 percent yellow birch.

SITE

Growth and yield of birch are related to site quality. The better the site, the faster the growth and the greater the yield.

Site-index curves (fig. 1) have been developed for paper and yellow birch, as well as for sugar maple and white ash, growing in Vermont *(Curtis and Post 1962b)*. These curves were found to be applicable to New Hampshire stands, with minor height corrections for precise estimation *(Solomon 1968)*.

In mixed stands, it may be necessary to use measured site index for one species to predict site index of another. Figure 2 shows the relationship among site indices of paper birch, yellow birch, sugar maple, and white ash *(adapted from Curtis and Post 1962a)*. For example, if the measured site index of yellow birch is 70, then the comparable site index for paper birch would be about 76 (fig. 2).

In New England, average site index for paper birch is about 60 to 70 feet. The potential production of a paper birch stand with a site index of 75 or better is high, while a site index of 55 or less represents fairly low potential. For yellow birch, average site index is 55 to 65, with a high of 70 or better and a low of 50 or less.

STOCKING

Even-aged and uneven-aged stands will be considered separately, because the measurement and interpretation of stocking differs between these two types of stands.

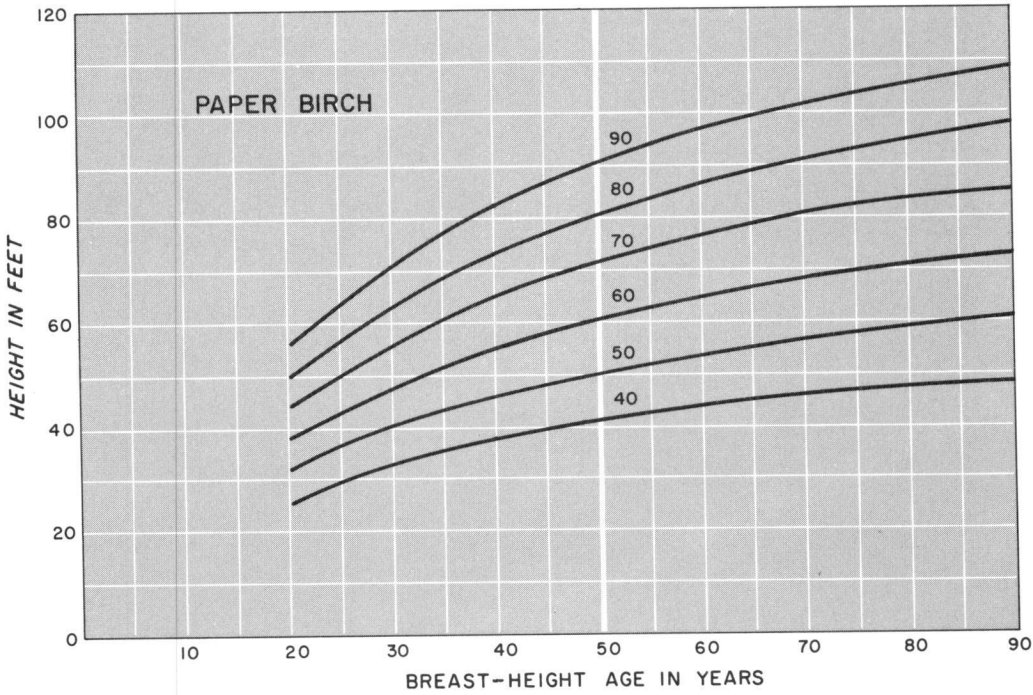
Uneven-Aged

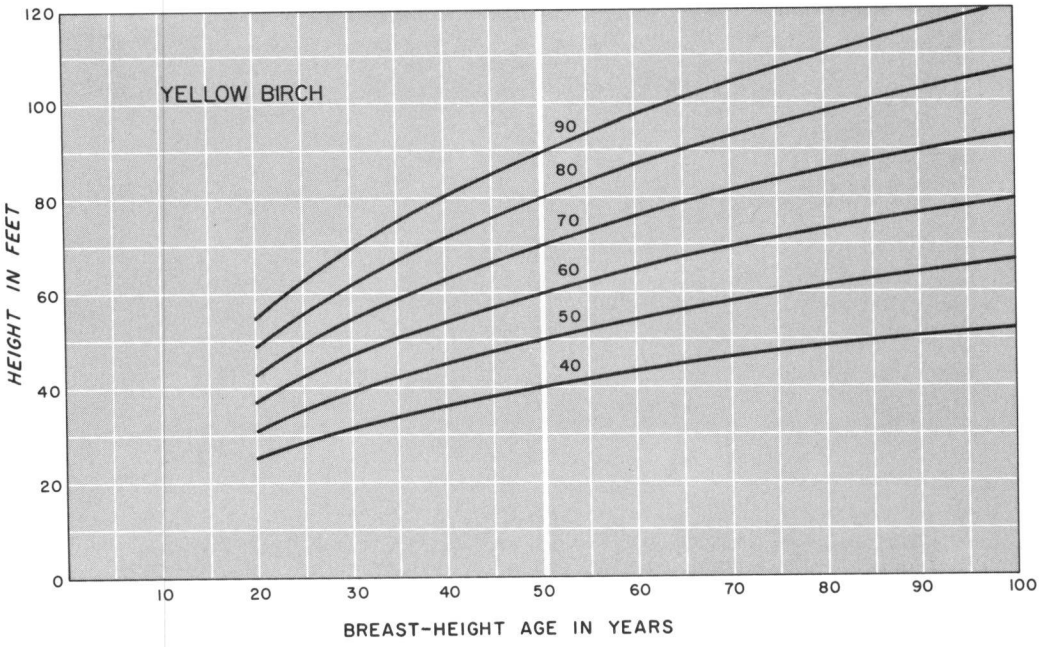
Uneven-aged northern hardwoods contain a mixture of hardwoods, including a small to medium proportion of yellow birch, but little or no paper birch.

Choice of an appropriate or optimum stocking level in uneven-aged hardwoods is best determined by examining the relationship of growth to stocking or density. Gross annual basal-area growth per acre in trees over 5.0 inches as related to average basal area per acre (at the midpoint of the cutting cycle) is depicted in figure 3. This curve is based on a series of cutting experiments in the White Mountains of New Hampshire. Because of the varying length of cutting cycle, basal area at the midpoint of the cycle was considered a better measure of density than residual (initial) basal area per acre.

Gross basal-area growth is at a maximum between 80 and 100 square feet of basal area. However, growth response is very acceptable between 70 and 110 square feet. Thus we usually recommend a residual basal area after cutting of between 70 to 80 square feet in trees 5.0 inches and larger. Numerous

Figure 1.—Site-index curves (breast-height age 50) for yellow birch and paper birch.





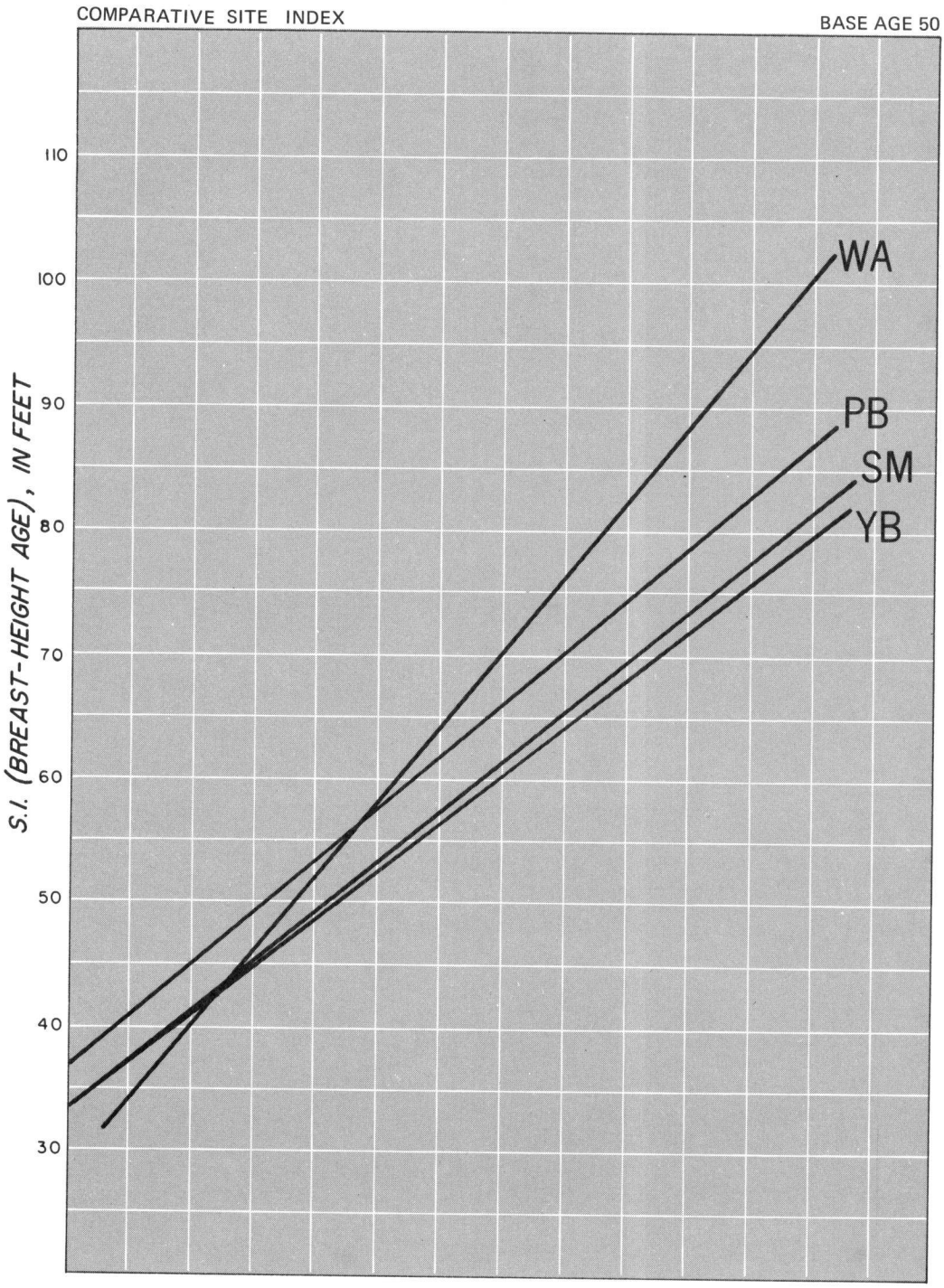


Figure 2.—Relationships among site index for four northern hardwoods. To estimate site index of species X from site index of species Y: find known site index on the curve for species Y; move vertically up or down to the curve for species X; read horizontally across to the left to find estimated site index for species X.

cutting experiments in New England indicate that losses in quality will not occur at residual basal areas within this range.

In addition to stocking, the stand structure —distribution of trees by d.b.h. classes— should also be controlled in uneven-aged stands. A typical structure for a stand at 80 square feet basal area is *(Gilbert and Jensen 1958)*:

2-inch d.b.h. class (inches)	*Trees (No.)*	*Basal area (sq. ft.)*
6 — 10	60	20
12 — 16	30	28
18 +	15	32
All	105	80

This is in close agreement with the results in northern hardwoods in the Lake States *(Arbogast 1957)*.

In applying cutting operations, an attempt should be made to work toward a structure similar to that outlined above. This will ensure that a high proportion of growth is placed upon sawtimber-sized trees. But sufficient smaller stems will be available to grow into the larger sizes.

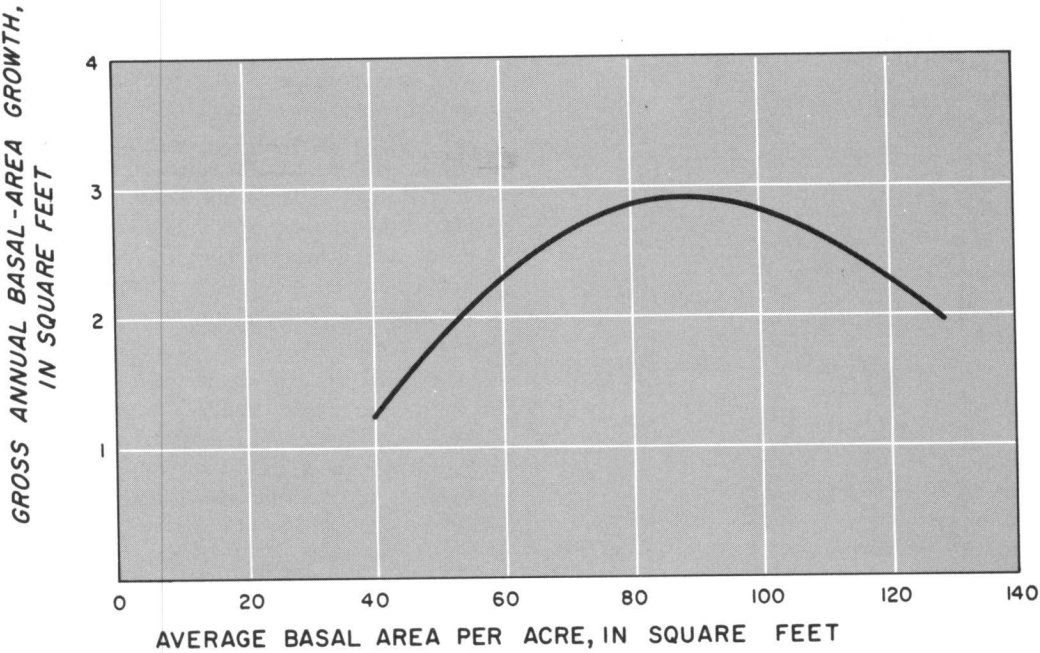
Even-Aged

Different methods are used to evaluate stocking in even-aged stands. An even-aged northern hardwoods stand usually contains a higher proportion of paper birch and yellow birch than an uneven-aged stand.

Sapling stands.—From plot tallies in unmanaged northern hardwood stands ranging from about 1.0 to 4.5 inches d.b.h., we determined the numbers of trees at a given initial diameter required to produce one tree at a given future diameter. Separate estimates were made for all commercial species, and for intolerant-intermediate species only. For example, average numbers of trees required to produce one tree when the species group reaches 5.0 inches mean d.b.h. are *(Leak 1969)*:

Initial mean d.b.h. (inches)	*Average numbers*	
	All commercial species (No.)	*Intolerants-intermediates (No.)*
1.0	5.3	3.7
2.0	3.6	2.7
3.0	2.3	1.9
4.0	1.5	1.4

Figure 3.—Relationship of gross annual basal area growth to average basal area per acre in trees over 5.0 inches d.b.h. for uneven-aged northern hardwoods (average site).



Using statistical theory, we also determined the initial numbers of trees required to produce one tree at mean d.b.h. 5.0 inches with a high degree of confidence, ≥ 0.85.

Initial mean d.b.h. (inches)	*High-confidence numbers*	
	All commercial species	*Intolerants-intermediates*
1.0	9	6
2.0	6	5
3.0	4	3
4.0	2	2

Stocking guides for older stands (to be discussed later), indicate that we should have a minimum of 387[1] well-distributed and well-formed northern hardwood or paper birch stems when the stand reaches mean d.b.h. 5.0 inches. Thus, if we sampled a stand using plots of 1/387 acre (113 square feet), it would seem reasonable to require that each plot contain at least the average number of good stems, or the high-confidence number required to produce at least one good stem when the stand reaches mean d.b.h. of 5.0 inches. Any plot that contains this minimum number is considered stocked. The percentage of stocked plots would reflect the percentage of the stand that was adequately stocked. Current recommendations are that 50 to 60 percent is adequate stocking.

Furthermore, using the average numbers and high-confidence numbers tabulated above, we can estimate the numbers of stems per acre required to produce 387 good stems at mean d.b.h. 5.0 for a northern hardwood or paper birch stand.

Initial mean d.b.h. (inches)	*Average numbers/acre*	
	All commercial	*Intolerants-intermediates*
1.0	2,051	1,432
2.0	1,393	1,045
3.0	890	736
4.0	580	542
	High-confidence numbers/acre	
	All commercial	*Intolerants-intermediates*
1.0	3,483	2,322
2.0	2,322	1,935
3.0	1,548	1,161
4.0	774	774

Any stand that did not contain enough stems to qualify as adequately stocked would be considered as high priority for a cleaning treatment, to reduce mortality among the limited numbers of good stems. Conversely, any stand that qualified as adequately stocked would not require a cleaning treatment, although cleaning might still be justified on the basis of an improved growth response.

Poletimber and sawtimber stands.—In applying thinning and improvement cuttings in even-aged northern hardwoods, stocking control is of utmost importance. Although gross growth per acre is approximately equal over a range of densities for stands of similar site and species composition, diameter growth of crop trees is much higher, and mortality much lower, under something less than normal stocking. Conversely, if stocking gets too low, growth per acre and quality decline.

Stocking guides have been developed, for paper birch stands (50 percent or more of the basal area in paper birch) and northern hardwood stands, showing numbers of trees and basal areas per acre for stands of various mean d.b.h. (figs. 4 and 5). These guides apply to the main crown canopy of the stand —trees in a dominant, codominant or intermediate crown position that are touching the main overstory.

In these guides, the A line represents an average unmanaged stand. The B line represents minimum stocking for full site utilization and adequate growth without competition. The C line represents the level where 10 years of growth on an average site will raise the standard to B line stocking.

Stands above the A line are overstocked. Stands between the A and B lines are adequately stocked. Stands between the B and C lines are potentially adequately stocked, and those below the C line are understocked. Under most conditions, stands are considered for thinning when stocking is more than halfway between the A and B lines. Stocking after thinning should be near (above or below) the B line.

The concepts used in evaluating stocking in both regeneration stands and older stands have been combined in figure 6 to produce a stocking chart for paper birch stands between 1 and 5 inches mean d.b.h. Here too

[1] As illustrated in figures 4 and 5, stands with a mean d.b.h. of 5.0 inches contain 387 trees per acre at minimum full stocking (B line).

the A line represents the development of an unmanaged stand. The B line represents desirable stocking after thinning or weeding.

GROWTH

Growth of both uneven-aged and even-aged stands in terms of diameter, basal area, and height is useful as a basis for evaluating response to silvicultural treatment, and for comparing species differences in growth response. Although growth measures are not necessarily in merchantable units, growth data frequently can be used for developing yield estimates.

Diameter Growth

Uneven-aged.—Diameter growth of northern hardwoods in cut and uncut uneven-aged stands is illustrated in figure 7. Basal area of the cut stand varied from 77 to 94 square feet over the 15-year growth period, while the basal area in the uncut stand varied from 110 to 115 square feet. In the smaller sizes, diameter growth of trees in the cut stand was at least twice as great as that in the uncut stand. In the larger sizes, diameter growth was somewhere around 20 to 25 percent greater under cutting *(Gilbert et al. 1955)*.

Yellow birch, which made up about 6 percent of the stand, grew somewhat slower than average, although they, too, responded to treatment. D.b.h. growth rates in the cut stand were:

Species	*Annual d.b.h. growth rate (treated) (inches)*
Hemlock	0.13
Sugar maple	0.14
Beech	0.13
Yellow birch	0.09

In addition to cutting treatment, individual characteristics related to tree vigor also affect diameter growth of yellow birch growing in uneven-aged stands. A sample of 200 yellow birch trees growing in essentially unmanaged stands were bored to determine past 5-year growth, and were rated for vigor according to the following classes:

Vigor Class I.—Trees with no injury and having dense crowns in a dominant or codominant position. One-half or more of the crown is exposed to full sunlight.

Vigor Class II.—Trees that are codominants or poor dominants, or with possible injury, and the crown is less than half exposed to full sunlight.

Figure 4.—Stocking guide for pure even-aged paper birch stands, showing basal area per acre, numbers of trees per acre, and mean d.b.h. for trees in the main crown canopy.

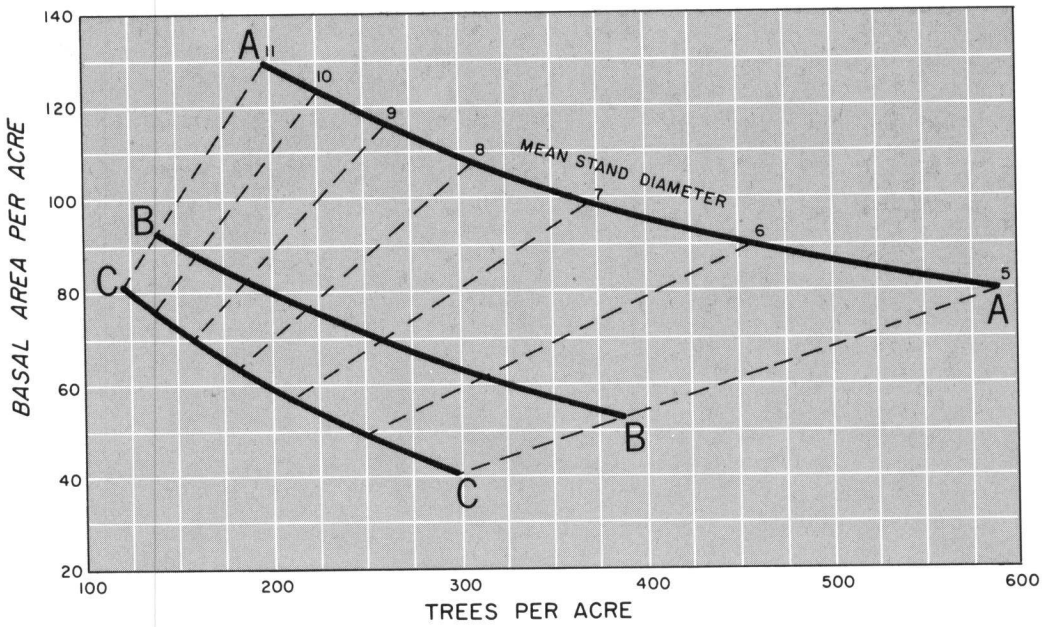
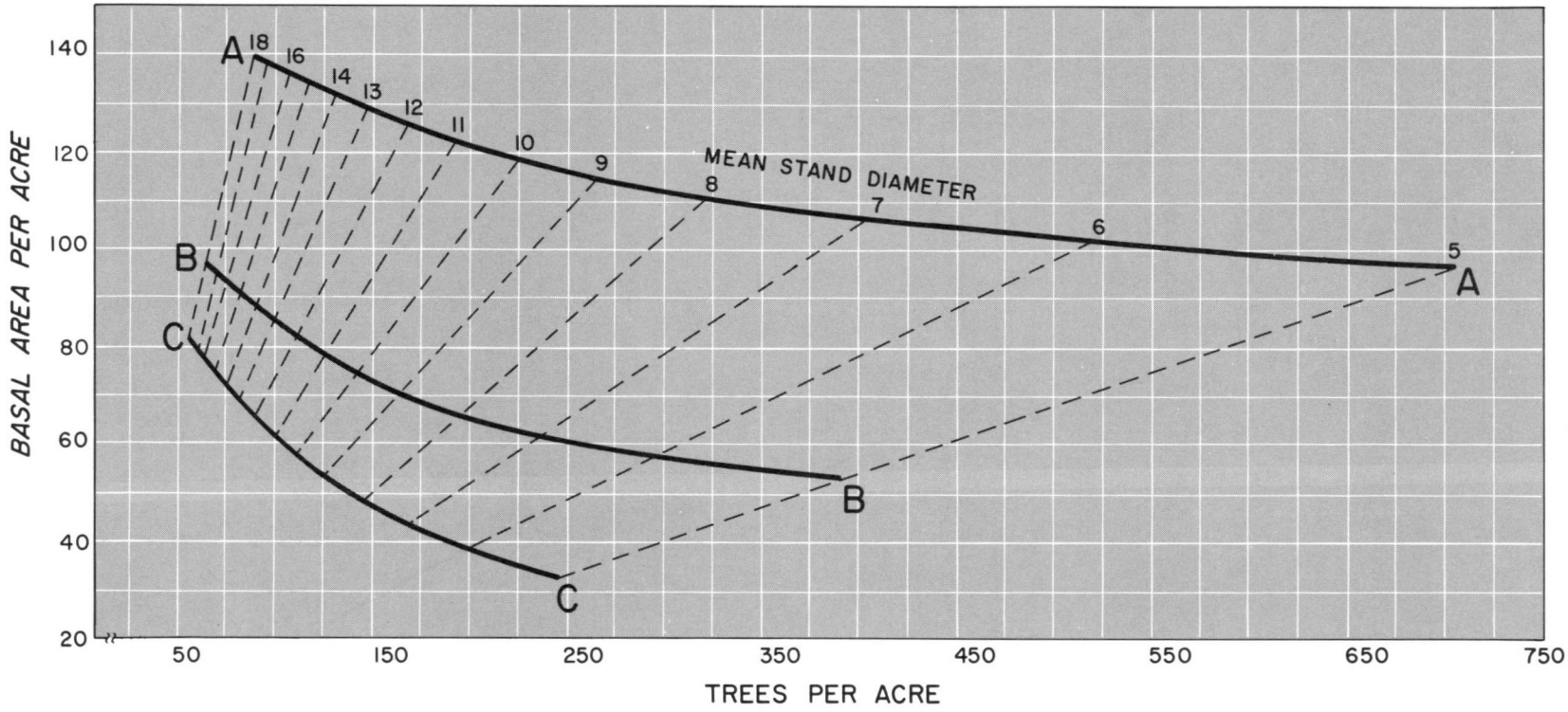


Figure 5.—Stocking guide for even-aged northern hardwood stands, showing basal area per acre, numbers of trees per acre, and mean d.b.h. for trees in the main crown canopy.



Vigor Class III.—Trees with a medium-size crown, usually in an intermediate position, with very little crown exposed to sunlight.

Vigor Class IV.—An overtopped and suppressed tree and any trees that do not meet the above class requirements.

Average annual diameter growth rates for yellow birch trees in these four vigor classes are given below, together with the standard deviation:

Vigor Class	*Average annual d.b.h. growth (inches)*	*Standard deviation (inches)*
I	0.087	0.018
II	0.075	0.011
III	0.068	0.010
IV	0.061	0.013

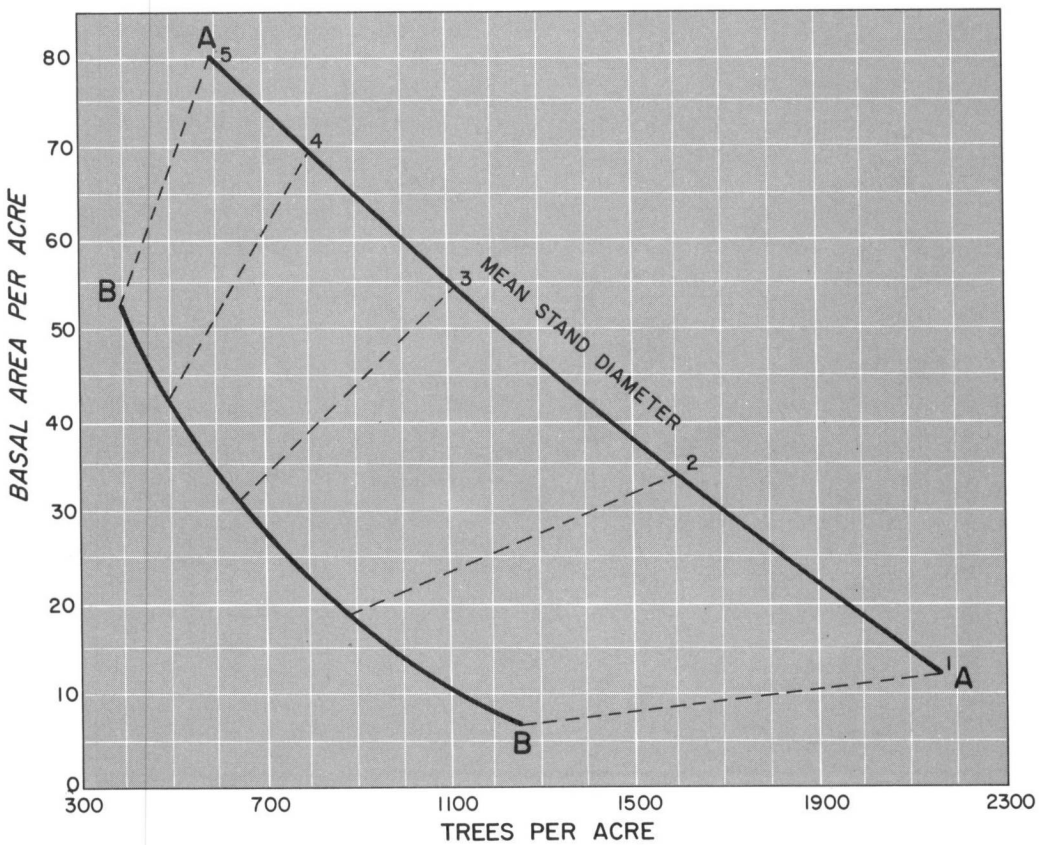
Trees in vigor class I grow on the average less than 1 inch in 10 years. Vigor I trees at two standard deviations above the mean have an estimated growth of only about 1.2 inches in 10 years.[2]

Even-aged.—Diameter growth rates of yellow and paper birch in even-aged stands vary considerably depending upon stand treatment, age, and site.

In unthinned northern hardwoods 25 years old on about site index 65 for sugar maple, diameter growth rate of yellow birch crop trees was found to be about 0.9 inch d.b.h. in 10 years, somewhat faster than that of beech and sugar maple, but slower than that of paper birch, white ash, and red maple. Under the same conditions, paper birch grew at 1.4 inches in 10 years, slightly less rapidly than white ash (table 1).

[2] Solomon, Dale S., and Stanley M. Filip. The prediction of diameter growth of yellow birch and log grades. 1968. Report on file at the Northeastern Forest Experiment Station, Durham, N.H.

Figure 6.—Stocking guide for even-aged sapling stands of paper birch.



After moderate thinning, which removed 25 to 30 percent of the basal area, d.b.h. growth of yellow birch increased only slightly to 1.0 or 1.1 inches in 10 years—slower than any other species except beech. Paper birch growth rate was 1.7 inches in 10 years, a little less than that of white ash and about the same as that of red maple. However, a heavy thinning, which removed about 40 percent of the basal area, increased yellow birch growth rates to 1.6 inches in 10 years, about 78 percent better than the unthinned rate. Paper birch growth rates were only slightly greater under heavy thinning as compared to moderate thinning.[3]

Thus, in young stands, yellow birch growth response is very appreciable after heavy thinning. Paper birch response is fair under both moderate and heavy thinning.

In a 65-year-old stand on a good site, paper and yellow birch growth rates after a moderate thinning of 20 to 30 percent were about 1 inch in 10 years, less than that of any other species *(Wilson 1953)*. After a second thinning in this stand (which removed the paper birch), the growth rate of yellow birch dropped to about 0.75 inch in 10 years. Apparently, after age 65, the ability of both paper and yellow birch to respond to thinning is less than at an earlier age.

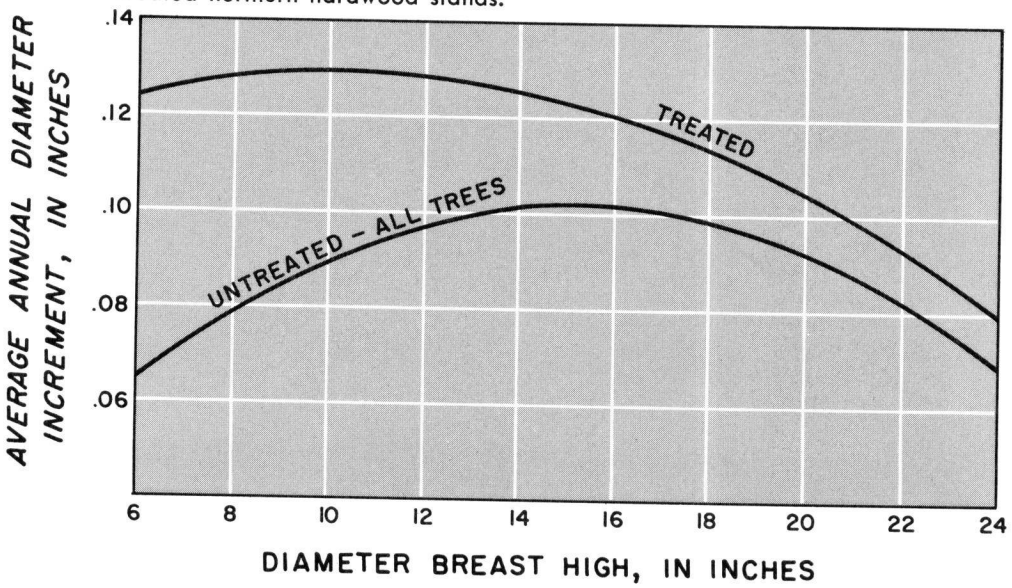
[3] Marquis, David A. Progress report: Response of a 25-year-old northern hardwood stand to early thinning. 84 pp. 1967. Report on file at Northeastern Forest Experiment Station, Durham, N.H.

Basal-Area Growth

Uneven-aged.—Gross basal area growth of uneven-aged stands tends to follow a parabolic curve, reaching a maximum of about 3 square feet (on a good site) at a moderate average density of 80 to 100 square feet (fig. 3). On less productive sites, gross basal area growth may be 2.0 to 2.5 square feet per acre per year. In uncut uneven-aged stands, mortality may be 70 percent or more of the gross growth *(Gilbert et al. 1955, Filip et al. 1960)*. In managed stands, mortality can usually be reduced to 35 percent or less of the gross growth. Thus observed production (net growth) rates commonly are 1.5 to 2.0 square feet per acre per year in northern hardwood stands of New England during the early stages of management. Similar growth rates apparently prevail in northern hardwoods of the Lake States *(Church 1960, Eyre and Zillgitt 1953)*.

In typical northern hardwoods, the basal-area growth attributable to yellow birch is somewhat less than proportional, because this species grows somewhat more slowly than the

Figure 7.—Average annual diameter increment in treated and untreated northern hardwood stands.



average. However, in mixed softwood stands, growth rates of yellow birch often are equal to or better than its common associates *(Leak 1961a)*.

Under uneven-aged management, a fairly large proportion of the total stand growth is placed upon trees in the sawtimber classes (11.0 inches d.b.h. and over). After several types of cutting in northern hardwoods, the following distribution of growth was observed *(Blum and Filip 1963)*:

Type of cutting	*Residual basal area (square feet)*	*Proportion of growth in sawtimber trees (percent)*
Light selection	95	86
Moderate selection	83	69
Diameter-limit	64	58

Even-aged.—Basal area growth in a typical mixed even-aged hardwood stand varies greatly with stand age. After thinning in young stands 25 years old, net basal-area growth rates up to 4 to 5 square feet per acre have been observed. Gross basal-area growth in these young stands may reach as high as 6 or 8 square feet.[3]

In older stands, gross basal-area growth usually falls within the range of 2.5 to 3.5 square feet. Net basal-area growth, or production, in unmanaged even-aged stands 50 to 70 years old was found to vary from 1.2 to 2.3 square feet, in inverse proportion to the density of stocking *(Leak 1961b)*. In thinned stands about 60 to 80 years old, net basal-area growth on good sites may attain about 2.5 square feet per acre *(Wilson 1953)*.

Height Growth

Height-growth patterns vary somewhat among the species commonly found in northern hardwood stands. In young stands about 25 years old, paper birch and white ash usually are the tallest of the commercial species (excluding aspen); yellow birch commonly is intermediate in height, a little taller than the average crop tree of sugar maple and beech.

In older stands, perhaps the most meaningful comparisons are in terms of site index, height of dominants and codominants at breast-height age 50. On a given area, paper birch site index consistently is 4 to 6 feet higher than those of sugar maple and yellow birch. These latter two species show similar site indexes over a range in site quality. On poor sites, white ash site index is about the same as those of the other species; however, on better sites, white ash site index may exceed those of the other species by 10 feet or more (fig. 2).

YIELD

Yield of a stand or a forest is expressed in terms of volumes or products that can be harvested. Yield figures are given separately for uneven-aged and even-aged stands.

Uneven-Aged

Based on a gross annual growth rate of 2.75 square feet per acre for a stand with 80 to 90 square feet average basal area per acre, and 25 percent loss to mortality, estimated yield of a well-balanced stand on an annual

Table 1.—*Annual d.b.h. growth rates for crop trees in a 25-year-old northern hardwood stand (initial age) under thinning of various intensities*

Species	Degree of thinning		
	None	Moderate (25-30%)	Heavy (40%)
	Inches	*Inches*	*Inches*
Paper birch	0.14	0.17	0.18
Yellow birch	.09	.10-.11	.16
White ash	.16	.18-.21	.22
Sugar maple	.06	.11-.13	.14
Red maple	.12	.16-.18	.20
Beech	.07	.09	.15
All	0.11	0.15	0.18

basis is about 200 board feet of sawlogs and veneer plus 15 cubic feet of pulpwood per acre. This total yield is equivalent to at least ½ cord per acre annually. Sustained yield potentials in managed uneven-aged stands in the Lake States are similar *(Eyre and Zillgitt 1953)*. The expected yield of yellow birch would, of course, be proportional to the amount of yellow birch in the stand.

Logging economics dictates a desirable cut per acre of 6 to 10 cords; thus the appropriate cutting cycle would be 12 to 20 years.

Clearcutting of uneven-aged stands, in preparation for some form of even-aged management, produces both heavy volume yields and a variety of products *(Filip 1967)*. The following products and volumes were obtained from clearcutting a 50-acre area on the Bartlett Experimental Forest *(Filip and Williams 1968)*.

Product	*Board feet per acre (or equivalent)*
Veneer logs (birch)	221
Handle stock (ash)	147
Bobbin stock (sugar maple)	1,987
Core logs (hardwood)	1,628
Pallet logs (hardwood, softwood)	924
Softwood logs	608
Millwood (birch)	448
Pulpwood (hardwood, softwood)	6,040
	12,003

Even-Aged

Gross yields in board feet or cubic feet from well-stocked even-aged paper birch and northern hardwood stands are given in tables 2 and 3. The cubic-foot yields are for trees 4.5 inches plus; the board-foot yields are for trees 10.5 inches plus. Yields are for average site conditions (site index 70 for paper birch, and 60 for northern hardwoods). For a different site, multiply the yields in tables 2 and 3 by S.I./70 or S.I./60 for paper birch and northern hardwoods, respectively. Yields for paper birch or yellow birch alone would be in proportion to species composition.

Years to reach various mean stand diameters are given for a range of site index under both managed and unmanaged conditions. The yearly figures for managed stands are considered attainable under currently feasible schedules of intermediate cutting.

Paper birch stands should be grown to a mean d.b.h. of 8 to 9 inches where boltwood is the objective, or to larger size if veneer or sawlogs are desired. Thus, the rotation age on site 60 would be 75 years or more without management and 60 years or more under management.

Northern hardwoods should be grown to a mean stand diameter of at least 13 to 14 inches d.b.h. This is equivalent to a rotation age (site index 60) of 120 or 160 years with or without management, respectively.

Table 2.—*Merchantable volume yields per acre for stands of various mean diameter, and years to reach various mean diameters by site index (breast height age 50), for pure paper birch stands under scheduled thinnings or no thinnings*

Mean [1] diameter	Merch. [2] volume per acre	Site index					
		50		60		70	
		Unthinned	Thinned	Unthinned	Thinned	Unthinned	Thinned
Inches	*Cubic feet*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*
5	900	43	34	35	28	27	22
6	1,390	53	42	43	34	33	26
7	1,870	65	52	53	42	38	30
8	2,560	79	63	62	50	47	38
9	3,170	95	76	75	60	58	46
10	3,830	—	89	90	72	70	56
11	4,240	—	—	—	86	85	67

[1] Trees 0.6 inches +.

[2] Merchantable volumes for site index 70. Volumes for site indexes other than 70 can be computed by multiplying the above yield by S.I./70. Volumes are to a 3- to 5-inch top d.i.b.

Under management, intermediate yields of northern hardwoods will be about equal to the yields shown in table 3. In other words, intermediate cuts will about double the yields. Although comparable estimates are not available for paper birch stands, evidence to date indicates that intermediate cuts will substantially increase the yields from paper birch stands as well.

SUMMARY

Available growth and yield information for yellow birch and paper birch growing as even-aged and uneven-aged northern hardwoods have been summarized, and guides for managing stands for their maximum potential have been presented.

Site estimation for both species in even-aged stands is facilitated by the availability of site-index curves, and a set of comparative site-index relationships.

Stocking guidelines for uneven-aged stands containing yellow birch, based on the relationship between gross basal-area growth and residual stocking, indicate that 70 to 80 square feet per acre (trees 5.0 inches plus) is a reasonable residual basal area after cutting.

Detailed stocking charts are presented for even-aged stands of pure paper birch and mixed northern hardwoods, showing basal areas, numbers of trees, and mean stand diameters that represent overstocked, adequately stocked, and understocked conditions.

Selection cutting in uneven-aged stands has been found to approximately double the average d.b.h. growth of the smaller stems, while the growth of larger stems increased by about 20 to 25 percent. Yellow birch in such stands, although responding well to cutting, grows considerably slower than other northern hardwood species. Individual tree characteristics, such as vigor, have an important influence upon diameter growth rates of yellow birch in uneven-aged stands.

After heavy thinning in 25-year-old even-aged northern hardwoods, diameter growth rates of paper birch and yellow birch increased by nearly 30 percent and over 75 percent, respectively. In older stands, past age 65, the response of both birches to thinning is considerably less.

Gross basal-area growth rates in uneven-aged stands reach a maximum of about 3 square feet per acre per year on good sites. In managed stands, mortality can be reduced to less than 35 percent, resulting in a net basal-area growth rate of about 2.0 square feet. Under selection cutting, from 70 to 85 percent of the net basal-area growth is in sawtimber-size trees.

In even-aged stands, gross basal-area growth rates vary from as high as 6 to 8 square feet in young stands about 25 years old, down to between 2.5 and 3.5 square feet in pole and sawtimber stands. Net basal-area growth in even-aged stands varies in inverse proportion to the density of stocking.

Yields from an average well-balanced uneven-aged stand are estimated at about 200

Table 3.—*Final yields per acre for a given mean stand diameter, and years to reach a given mean diameter, by site index for mixed northern hardwood stands under scheduled thinnings or no thinnings*

Mean [1] d.b.h.	Volume/acre [2]		Basal area	Site index					
				50		60		70	
				Unthinned	Thinned	Unthinned	Thinned	Unthinned	Thinned
Inches	*Bd. ft.*	*Cu. ft.*	*Sq. ft.*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*
5.0	—	1,900	95	59	44	50	38	44	33
6.0	—	2,142	102	74	56	61	46	52	39
7.0	3,782	2,332	106	89	67	74	56	60	45
8.0	5,456	2,530	110	103	77	88	66	71	53
9.0	7,182	2,736	114	124	93	102	77	82	62
10.0	9,088	2,950	118	149	112	118	89	94	71
11.0	11,050	3,146	121	179	134	132	99	106	80
12.0	13,200	3,375	125	—	—	147	110	117	88
13.0	15,544	3,612	129	—	—	163	122	129	97
14.0	16,048	3,799	131	—	—	182	137	142	107
15.0	16,698	4,020	134	—	—	—	—	157	118

[1] Trees in the main canopy.
[2] Merchantable volumes for site index 60. Volumes for site indexes other than 60 can be computed by multiplying the above yield by S.I./60. Board-foot or cubic-foot volumes are to an 8-inch or 4-inch top d.i.b., respectively.

board feet of sawlogs per acre per year plus 15 cubic feet of pulpwood—equivalent to a total of at least one-half cord. Since current logging economics dictate a cut per acre of 6 to 10 cords, the appropriate cutting cycle is 12 to 20 years.

Harvest yields are presented in tabular form for even-aged mixed northern hardwoods and paper birch stands over a range in site quality. Preliminary estimates indicate that intermediate cuttings will as much as double the final yield from even-aged stands.

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