

SILVICAL REQUIREMENTS FOR NATURAL BIRCH REGENERATION

by DAVID A. MARQUIS, *Silviculturist, Northeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Upper Darby, Pa.*

A SCARCITY OF BIRCH REGENERATION

YOUNG STANDS of either paper birch or yellow birch are relatively scarce in the northern hardwood region today, primarily because birch has not regenerated with the silvicultural practices used over the past 30 or 40 years.

Where light cuttings and uneven-aged management have been used, the birches have gradually been eliminated in favor of more tolerant species. By now, I think most of us would agree that some form of even-aged management is required where we want to grow large proportions of the birches. But having reached this conclusion, can we assume that we will automatically get birch regeneration just by clearcutting? Or will special cutting methods or supplemental cultural techniques be required?

There have been *some* heavy cuttings in northern hardwoods over the years, both commercial and experimental. Regeneration obtained on many of these areas has been good. But on others, the birch has not come through as well as we might like. We could probably find examples ranging all the way from smashing successes to dismal failures.

Why have the results varied so widely? What factors have affected the results? What conditions must we provide to insure that prompt and adequate birch regeneration will be obtained? During the next few minutes, I'd like to describe some of our research on the silvical requirements for natural birch regeneration, and then show how we can provide the desired conditions through our choice of silvicultural technique. The three speakers

who follow will comment further on the importance of these factors in their respective regions, and they will describe results obtained from actual use of the various techniques.

FACTORS AFFECTING REGENERATION

To obtain birch regeneration, there are really only two major requirements. First, an adequate supply of seed must be delivered to the desired location at the appropriate time.¹ Second, the moisture, temperature, light, nutrients, and other environmental factors must be conducive to seed germination and seedling survival and growth.

Seed Supply

Both paper and yellow birch are generally considered to be prolific seeders, producing large quantities of seed that may be dispersed fairly long distances by the wind. Many of us have observed birch seedlings that have become established a considerable distance from the nearest known seed source. Yet seed supply is probably a limiting factor more often than we realize.

The quantities of seed produced each year vary tremendously. The 1955 seed crop in a 70-year-old paper birch stand in Massachusetts (*Bjorkbom et al. 1965*) was estimated at about 36 million seeds to the acre. At the other extreme, complete seed failures occasionally occur. Average seedfall from a well-stocked stand is probably between 1 and 2 million seeds per acre.

¹ Although the birches—particularly paper birch—often reproduce by sprouting, such sprouts seldom represent more than a small proportion of the new stems.

A review of annual seed-crop reports from the Lake States and the Northeast reveals that, out of every 10 years, both paper and yellow birch average about 1 heavy seed year, 3½ medium years, 4½ light or very light years, and 1 year of seed failure.² Thus medium or better crops occur a little less than 1 year in 2, but heavy crops occur only about 1 year in 10.

Quality of seed varies from year to year too. Seed viability is usually high during years of a heavy seed crop, but may be low during years of light crops. A study in Maine revealed germination of 77 percent during a heavy seed year versus germination of 13 and 24 percent during two more normal years (Bjorkbom *et al.* 1965). Thus viability is low during years when seed supply is already limited.

Low seed viability during certain years may be related to incomplete fertilization, resulting from either poor flower crops or adverse weather conditions at the time of pollination. The birches are known to be parthenocarpic: pistillate flowers develop into a fruit regardless of whether or not fertilization has occurred (Sarvas 1952, Frovola 1956). This of course results in empty seed coats. The importance of this was illustrated in a study of birch seed crops in Canada. Although the 1951 seed crop was about average size, none of the seeds examined contained embryos (Redmond and Robinson 1954). Thus, there may be a complete failure of viable seeds, even though seedfall is observed.

Insects and diseases also reduce viability of birch seed. Larvae of various insects have been found in birch catkins. They consume many seeds and may provide entrance for fungi. During an outbreak of the weevil *Apion walshii* in 1961 in New Hampshire, it was estimated that about half of the yellow birch seeds were damaged by this insect. Fungi reducing viability or affecting the new seedlings have also been found in catkins that have not been attacked by insects (Shigo and Yelenosky 1963).

Birch seed matures during late summer and is dispersed throughout the late summer, fall, and winter months. Although birch seed is very light in weight, its wings are inefficient

in sustaining flight. Sarvas (1948) found that the rate of fall of European birch seed (0.52 to 0.67 meters/sec) was no slower than that of the much heavier Scotch pine (0.65 meters/sec).

Although individual birch seeds may be dispersed long distances if caught in high winds or blown over crusted snow, quantity dispersal is usually limited to a distance of about two times the height of the seed-producing trees (Sarvas 1948). In a study of paper birch dispersal in Maine, seedfall two tree heights from the bordering seed trees was only about 15 percent of that within the stand.³ Seed weight and germinability also varied with dispersal distance, the heaviest and best seeds falling closest to the seed trees.

Thus the quantity of viable birch seed present actually varies over a wide range. During a bumper seed year tremendous quantities are available, the viability is high, and seedfall should be adequate for regeneration considerable distances from the source. In poor years, however, quantities are limited, viability is low, and seedfall at distances of more than about 150 feet from the seed source is apt to be inadequate for regeneration of stands containing large quantities of birch.

What can we do about seed supply? The first thing we can do is learn to predict the seed crop in advance so that we will know whether or not seed supply is apt to be a limiting factor. This is not as difficult as you might expect. The staminate or male catkins are formed in midsummer. They remain on the tree over the winter and then open after considerable elongation in the spring, at which time their pollen is released and the female flowers are pollinated. The fertilized female ovules then develop into seeds, which are dispersed in the fall. During the winter months, the male catkins average about 1 inch long and are clearly visible from the ground. Their relative abundance at this time is a good guide to the size of the seed crop the following fall—barring unforeseen catastrophies to either male or female catkins. Thus, an estimate of male catkin abundance made in November 1969 would provide a guide to the seed crop in the fall of 1970 and could be

² Marquis, David A. THE SEEDING HABITS OF PAPER AND YELLOW BIRCH. Unpublished report, NE. Forest Exp. Sta., 33 pp., 1963.

³ Bjorkbom, John C. PAPER BIRCH SEED PRODUCTION, DISPERSAL, AND GERMINATION. Manuscript in preparation, NE. Forest Exp. Sta., 1969.

useful in scheduling cutting operations through the spring of 1971.

Armed with knowledge that the seed crop of a particular year is liable to be small, we might take any of several actions. Perhaps the cuttings can be rescheduled so as to avoid the problem. One obvious way is to postpone regeneration cuts to a year of better seed crops; this usually requires just a 1-year postponement. If postponement is not possible, the actual felling operation could be scheduled to take best advantage of the seed that is available. If the cuttings take place between late fall and early spring, seed dispersed from these trees before cutting will be available in the spring to provide for regeneration. However, if cutting is done during the summer months—after the seed from the previous fall is gone and before the new crop is ripened—there will be little seed in the humus to establish a new stand and seed dispersal from the surrounding trees might not be adequate if the opening is large.

Where fall or winter cutting is undesirable or impractical, it may be necessary to retain seed trees, either as individual trees in large clearcuttings or as border trees along small openings. Considering effective dispersal distances during poor seed years, we recommend up to four well-distributed birch seed trees per acre in large clearcuttings, or limiting of openings to a maximum width of 300 feet.

Still another way to take advantage of a limited seed crop is to provide optimum conditions for seed germination. This brings us to the second of our two requirements for birch regeneration.

Environmental Conditions

The small size of the birch seed makes it especially sensitive to environmental conditions at the time of germination. A paper birch seed weighs only about 1/50 as much as a white pine seed, or only about 1/200 as much as a sugar maple seed. The newly germinated seedling is likewise small and extremely sensitive to environmental conditions for the first few months.

Soil moisture and soil temperature are the factors that most directly affect seed germination and early seedling survival. Weather conditions, soil and seedbed type, and exposure to sunlight in turn affect the soil moisture and temperature regime.

The environments that birch seeds find on

cutover lands vary tremendously. Among the more or less stable site factors that have important effects are aspect and soil drainage. Although neither of these factors has been evaluated quantitatively in terms of regeneration, we know something of their effects. For example, southwest aspects are generally drier and hotter than northeast aspects. Excessively drained soils are usually droughty, so they are less favorable for birch regeneration than others. In contrast, poorly drained soils may have more abundant moisture and therefore may be more favorable for seed germination. Both aspect and soil drainage have also been shown to affect productivity of the trees once they are established.⁴

Of course weather conditions affect germination and survival too. We have found germination to be nearly twice as high during a year with a wet spring as it was during a year with more normal precipitation (*Marquis et al.* 1964).

On any particular site during any year, the condition of the seedbed and the amount of exposure to direct sunlight are extremely important in affecting germination and early survival. Seedbed conditions after cutting vary from undisturbed leaf litter and humus to pure mineral soil, depending upon the amount of ground disturbance from skidding. And sunlight exposure may vary from full sunlight—as in a large clearcutting—to fairly dense shade—as in the border of a small opening or under the canopy of residual trees left after a partial or shelterwood cutting.

Best germination and early survival occur where mineral soil has been exposed and where there is shade. In some of our studies at Bartlett, we found that the number of paper birch seedlings present on mineral soil after 1 year was about 15 times greater than the number on leaf litter and about 3 times greater than the number on unloosened humus. Likewise, the number present was about 2½ times greater in the shade than in the sun (Fig. 1). On many of the leaf litter seedbeds exposed to full sunlight, no seedlings survived after one growing season (*Marquis et al.* 1964). Similar results have been re-

⁴ Post, Boyd W., and Robert Curtis. SITE CHARACTERISTICS AND SITE INDICES OF NORTHERN HARDWOODS IN THE GREEN MOUNTAINS OF VERMONT. Manuscript in preparation, Vt. Agr. Exp. Sta.

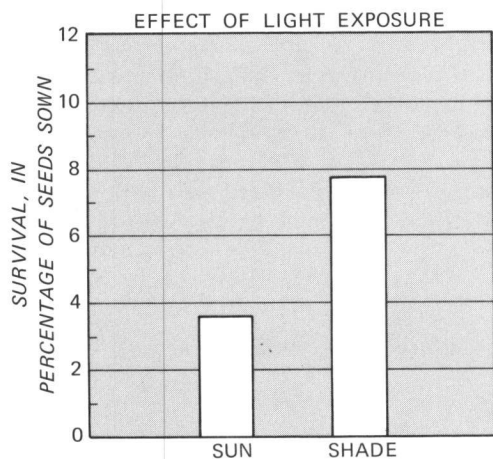
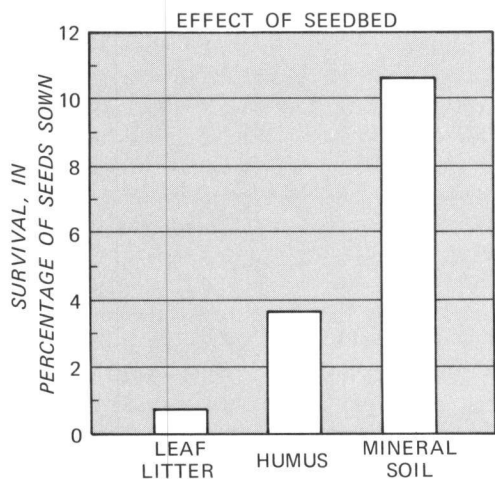


Figure 1.—Number of paper birch seedlings surviving after one growing season, as affected by seedbed and light exposure.

ported by numerous others for both paper and yellow birch.

One of the key factors in these seedbed and light exposure effects is soil moisture. Good germination and survival occur almost any place where moisture is high. In the previously mentioned study, surface moisture remained substantially higher throughout the growing season on the mineral soil seedbeds than it did on the humus and leaf litter seedbeds, particularly where the seedbeds were exposed to direct sunlight. Available moisture also remained higher in shady loca-

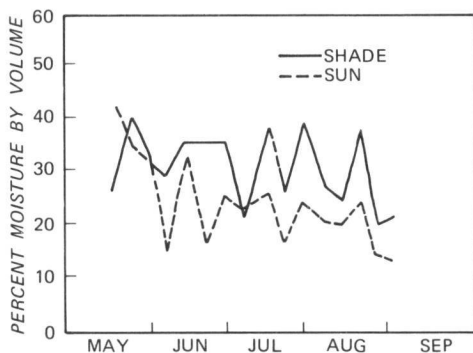
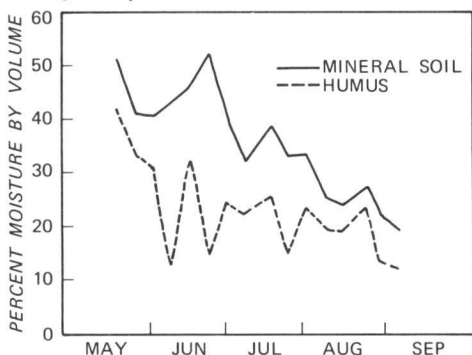
tions than it did in sunny locations (fig. 2).

That these differences are due mainly to moisture can be demonstrated by artificial watering. When this is done, germination and early survival are about the same in direct sun as they are under shade (*Marquis 1966*). Likewise, germination is uniformly good over a wide variety of seedbed types if moisture is artificially maintained at a high level⁵ (*Winget and Kozlowski 1965*).

Soil temperature also affects the responses to seedbeds and light exposures. Very high surface temperatures may be a direct cause of seedling mortality in some cases; we have recorded surface temperatures of over 150°F. on humus seedbeds exposed to full sunlight.

⁵ Tubbs, Carl H. THE INFLUENCE OF LIGHT, MOISTURE, AND SEEDBED ON YELLOW BIRCH REGENERATION. Manuscript in preparation, North Cent. Forest Exp. Sta.

Figure 2.—Soil moisture near the soil surface in a patch cutting, as affected by seedbed and light exposure.



But generally soil moisture and soil temperature are so closely interrelated that the effects of the two cannot be separated. As long as the soil moisture is high, soil temperatures remain moderate. Extremely high soil temperatures occur only when soil moisture has dropped to a very low level (fig. 3) (*Marquis 1967*). Thus it is not surprising that surface temperatures go extremely high on dry humus seedbeds exposed to direct sunlight, or that they remain relatively moderate (generally below 100°F.) in shaded areas, or on moist mineral seedbeds.

Growth is also affected by seedbed and light exposure. Growth is generally not as good on mineral soil as it is on the organic seedbeds. This difference is apparently due to low nutrient levels, or nutrient imbalances, in the mineral soil. The humus layers are relatively rich in nutrients and support good birch growth. *Tubbs (1965)*, *Hoyle (1965)* and *Winget and Kozlowski (1965)* have all demonstrated the differences in yellow birch growth that occur between the organic and mineral horizons in soils on which birch commonly grows.

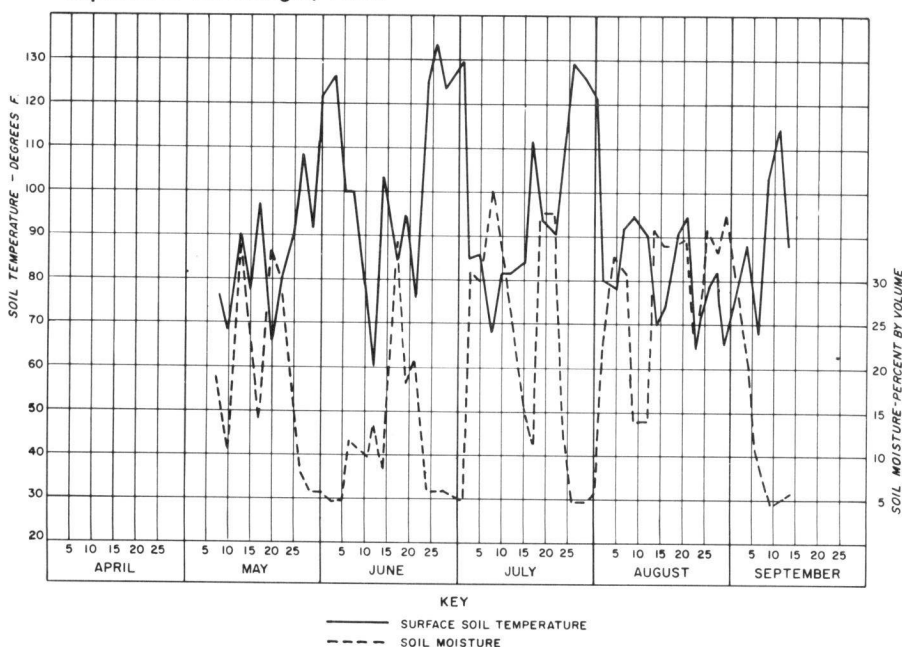
Growth of birch seedlings generally increases with increased light exposure, at least

up to a point. This effect is especially apparent with root growth. Root growth of both paper and yellow birch is greatest in full sunlight, but less in shade. *Logan (1965)* found significant reduction in root growth of both species at light levels below 45 percent full sunlight. And I have found that root-shoot ratio of paper birch is reduced nearly 3 times and of yellow birch nearly 2 times by shade levels of 43 to 66 percent of full sunlight (*Marquis 1966*) (fig. 4).

Reductions in root growth under shade may be especially important where the birches are competing with other species. Roots of some of the more tolerant species—such as sugar maple—are not significantly reduced by shade, so that these tolerant species are better able to compete for the limited growing space under shaded conditions (*Logan 1965*). The birches often fall behind the other vegetation under these conditions.

However, moderate shade during the first few years may not significantly reduce height or dry weight growth. In fact, moderate shade may be beneficial during this period, particularly for yellow birch. Results of numerous studies on this effect have given varied results, but light levels of between 50 and

Figure 3.—Soil moisture and soil temperature on a sandy loam soil exposed to full sunlight, 1963.



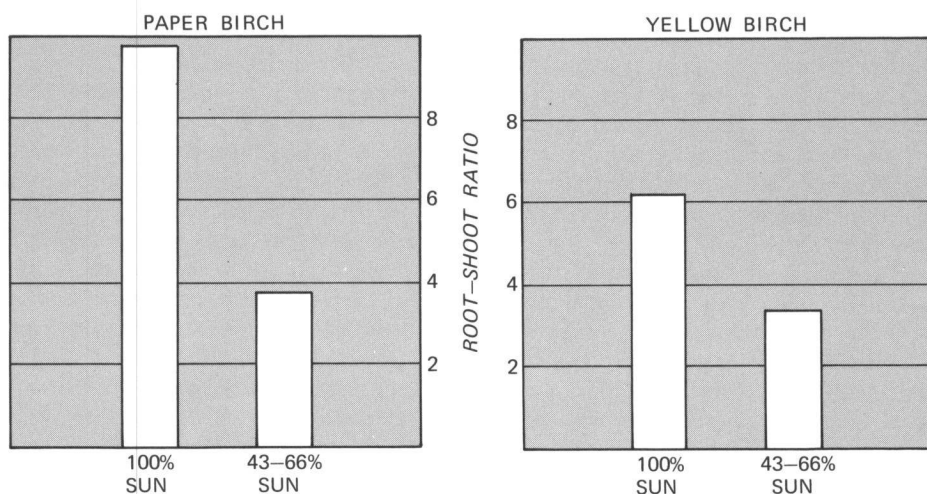


Figure 4.—Root-shoot ratio of birch seedlings after one growing season under varying degrees of shade.

100 percent of full sunlight generally seem best. Paper birch seems to do better nearer the 100-percent level, while yellow birch grows better at intensities closer to the 50-percent level⁵ (Logan 1965, Godman and Krefting 1960, Marquis 1966). It must be remembered that most of these results were obtained under controlled study conditions, with no competition among species. Under more natural conditions competition would be a factor, and the reduced root growth under shade would probably have an effect.

It seems to me that best growth and development of birch regeneration would be obtained by providing moderate shade for the first few years, and then increasing the amount of light as the seedlings enter into active competition with other species.

In attempting to provide the optimum conditions for birch regeneration, we are faced with several conflicts. Whereas germination and survival are best on mineral-soil seedbeds in deep shade, growth and development are better on humus seedbeds and in moderate shade or full sunlight.

The ideal seedbed would be one in which the mineral soil is exposed but in which the humus has been retained. The humus would be mixed with the mineral soil rather than scraped away. Such a seedbed preserves the nutrients of the humus for good growth and still provides the desirable moisture and temperature characteristics of mineral soil. De-

liberate soil scarification to obtain such seedbeds would materially increase the amount of birch in the regeneration.

Some scarification is obtained as a byproduct of logging, but the amount scarified in this way is generally inadequate. In our experimental patch cuttings, we found exposed mineral soil on only about 10 percent of the cutover area, and this was not well distributed but was concentrated in the skid trails (Marquis and Bjorkbom 1960). Even smaller amounts of scarification have been reported from Lake States selection cuttings (Church 1961).

Logging during the summer, and the use of narrow strips to channel skidding, both increase the proportion of the area scarified. I understand that the White Mountain National Forest has been at least partly successful in obtaining good scarification on some of their summer-logged sales by encouraging their operators to scarify as much as possible during their normal activities. Nevertheless, additional scarification would often be desirable.

Since light exposure can be controlled to a degree by the type of cutting used, we also have the opportunity to provide the best possible light environment. This can be done in several ways. One way is to use a partial cutting or shelterwood cutting to retain a certain amount of shade for germination. After a period of establishment, the residual stand could be reduced further or eliminated entirely depending upon the amount of light

desired for best growth. Such a technique provides somewhat irregular overhead shade.

Another technique is to use very small or narrow clearcuttings. The open shade (usually about 15 to 20 percent of full sunlight) found around the borders of these openings provides excellent conditions for germination and early survival. Additional light can be provided after the seedlings are established by cutting new openings adjacent to the original ones.

In a north-south oriented strip, the ground is shaded in the morning and afternoon, with a period of exposure to sunlight during the middle of the day, which varies with strip width. In New Hampshire, on level ground, a 70-foot-wide strip with 70-foot tall border trees receives about $3\frac{1}{2}$ hours of direct sunlight in June, while a strip 35 feet wide receives about 2 hours of direct sunlight (Marquis 1965). Light exposure in these strips averages 40 to 75 percent of full sunlight (Berry 1964).

An east-west strip receives shade during the middle of the day. To be completely shaded during the middle 4 hours of the day, east-west strips should be no more than about 25 feet wide. Areas beyond 30 feet from the south edge in east-west strips receive very nearly full sunlight. Light exposure in the southern 25-foot area of east-west strips averages 25 to 50 percent of full sunlight.

Northwest-southeast strips are exposed to full sunlight about 10:30 in the morning, when the sun shines directly down the long axis; but these strips are shaded during the hot afternoon hours. A 40-foot wide northwest-southeast strip receives about $2\frac{1}{2}$ hours of sunlight in the morning.

When strips are used, the heavy shade from the border trees is desired only for a few years while the new seedlings are becoming established. After that, a new strip should be cut adjacent to the original strip to provide the established seedlings with additional light.

PUTTING IT ALL TOGETHER

To review briefly, seed supply and environmental characteristics of the seedbed determine the amount of birch regeneration obtained. Proper scheduling of the cutting and retention of seed trees in or bordering the cutting area will reduce failures due to lack of seed. The use of cuttings that provide shade and the scarification of seedbeds will

increase germination and survival. Good luck with weather will also help.

Although it is relatively easy to say that certain measures will increase birch regeneration, it is much more difficult to determine when their use is required. Expensive or time-consuming special measures are certainly not justified in situations where regeneration would be adequate without them. Unfortunately, there are such wide variations in so many different factors that it is difficult to predict when scarification, strip cutting, seed trees, or other measures will be required.

We might calculate the number of birch seedlings that will be obtained under different circumstances by starting with various assumed numbers of seeds and reducing these numbers by various percentages corresponding to estimates of the viability of the seed crop, estimates of germination and survival, and similar factors. In the following example (table 1), I have assumed four classes of seed crops, 2 amounts of insect-disease damage to this seed, and 4 amounts of reduction in seed quantity due to dispersal distance. Likewise, I have recognized 2 groups of sites, 3 groups of weather conditions, and 4 groups of seedbed-light exposures that could affect germination and survival during the first year. Two classes of competition are also recognized as affecting survival during years 1 through 5.

The values used for each of these classes represent my own judgment as based on research results and published information. Where differences occur between paper birch and yellow birch, I have used values appropriate for paper birch. Although you can argue with any or all of these values, they are probably all in the right ball park.

With these assumptions and figures, I simply calculated the number of birch seedlings that might be present at 5 years of age for each of the various combinations of conditions. There are 1,536 possible combinations of conditions represented here. The number of seedlings calculated varied from 608,000 per acre in the best possible combination (which would probably never occur) to 8 per acre in the worst possible combination. I believe this illustrates rather dramatically the extreme variation that can be encountered in attempts to obtain birch regeneration.

If we assume some minimum number of birch seedlings required at 5 years of age to be considered successful, we can determine

Table 1.—Assumptions used in calculation of regeneration success.

SEED SUPPLY	
1. Seed crop, in number of <i>viable</i> seed per acre:	
a. Bumper (15,000,000)	
b. Average (1,000,000)	
c. Poor (500,000)	
d. Very poor (250,000)	
2. Proportion of seed not damaged by insects-fungi:	
a. 90%	
b. 50%	
3. Proportion of seed obtained at various dispersal distances:	
a. within 25 feet (100%)	
b. 25 to 40 feet (50%)	
c. 40 to 100 feet (35%)	
d. 100 to 200 feet (15%)	
ENVIRONMENT	
Proportion of seed germinating and surviving ¹ under various conditions of:	
4. Site:	
a. Average (100%)	
b. Unfavorable (50%)	
(South or southwest aspect or somewhat excessively drained soil.)	
5. Weather:	
a. Wet (150%)	
b. Average (100%)	
c. Dry (50%)	
6. Micro-environment:	
a. Shaded-scarified (12%)	
b. Shaded-unscarified (5%)	
c. Unshaded-scarified (7%)	
d. Unshaded-unscarified (3%)	
7. Competition during years 1 to 5:	
a. Average (50%)	
b. Severe (25%)	

¹ Germination and survival figures for micro-environment (item 6) are based on averages from field studies on the Bartlett Experimental Forest under conditions of average site and average weather. Figures for other weather or site conditions (4) and (5) are adjustments to the average figures given in item (6).

which combinations of conditions produce success. I have used a figure of 2,500 birch seedlings per acre as the minimum number required. This figure was calculated from estimates of tree drop-out rate (Leak 1969)

for paper birch stems in stands <0.6 inches average diameter (Marquis *et al.* 1969) We might also recognize another level where the number of birch stems is below the successful level but above some minimum level at which failure is virtually assured. Investments in special regeneration measures such as soil scarification, use of narrow strip cuttings, or retention of seed trees would be absolutely necessary to reproduce birch under these circumstances. I have subjectively set this level at 500 birch seedlings per acre at 5 years of age.

Selected results of these calculations are shown in table 2. It can be seen that clear-cuttings will fail to provide adequate regeneration if there is a poor seed crop. Failure may also occur during average seed years on sites where soil type or aspect are unfavorable, especially if the weather is unusually dry or there is extensive insect damage to the seed crop, or if severe competition develops from other tree species. Retention of seed trees on the clearcut area, or logging in winter or spring after natural seedfall improves the chances of success, as does use of supplemental scarification, or strip cutting. Strip cutting with seedbed scarification virtually assures successful birch regeneration under all but the most unusual conditions.

Although not shown in the table, bumper seed crops resulted in successful regeneration under all circumstances. Seed supply proved to be the single most important factor affecting results. This is due to the extreme variation that occurs in seed production.

Silvicultural recommendations based in part on these calculations have been incorporated into a published guide for paper birch. A similar guide for northern hardwoods—including yellow birch—has also been prepared.

The calculations just presented are extremely crude, but they illustrate the sort of approach now being used to develop much more accurate estimates of regeneration. Computer simulation studies, using much more sophisticated models of the birch regeneration process (Leak 1968), are now being undertaken by William B. Leak of our silviculture research unit at Durham; they will enable us to refine our silvicultural recommendations and provide more useful guides to the regeneration of these two valuable species.

Table 2.—Success of birch regeneration under various combinations of seed supply and environment.

Silviculture practice	Seed crop			
	Average site		Unfavorable site	
	Average	Poor	Average	Poor
1. Clearcutting				
a. Seed from bordering stand (summer logging), no scarification.	?	F	??	F
b. Seed from bordering stand (summer logging), with seedbed scarification.	S	??	?	F
c. Seed source on area (winter logging or seed trees), no scarification.	S	?	S	??
d. Seed source on area (winter logging or seed trees), with scarification.	S	S	S	?
2. Strip cutting (50 feet wide, east-west), logging either summer or winter.				
a. No scarification, seed from both borders.	S	S	S	?
b. Seedbed scarification, seed from both borders.	S	S	S	S

F = Expect regeneration failure (<500 paper birch seedlings per acre).

S = Expect regeneration success (>2,500 paper birch seedlings per acre).

?, ?? = Questionable regeneration success (500 to 2,500 paper birch seedlings per acre). Two question marks indicate that dry weather, heavy seed losses to insects or fungi, or more serious than average competition will reduce regeneration below 500 birch seedlings per acre. One question mark indicates that two of these three events combined would reduce regeneration below 500 birch seedlings per acre.

LITERATURE CITED

- Berry, A. B.
1964. EFFECT OF STRIP WIDTH ON PROPORTION OF DAILY LIGHT REACHING THE GROUND. *Forestry Chron.* 40(1): 130-131.
- Bjorkbom, John C., David A. Marquis, and Frank E. Cunningham.
1965. THE VARIABILITY OF PAPER BIRCH SEED PRODUCTION, DISPERSAL AND GERMINATION. USDA Forest Serv. Res. Paper NE-41, 8 pp., illus. NE Forest Exp. Sta., Upper Darby, Pa.
- Church, Thomas W., Jr.
1961. SEASON OF LOGGING UNIMPORTANT IN CREATING DISTURBED SEEDBEDS FOR YELLOW BIRCH. USDA Forest Serv. Lake States Forest Exp. Sta. Tech. Note 605, 2 pp. St. Paul, Minn.
- Frolova, G. D.
1956. THE BIOLOGY OF FLOWERING IN SOME BIRCHES. *Forestry Abstracts* 1386, vol 18. From *Botanicheski Zhurnal.* (Russian.)
- Godman, Richard M., and Laurits W. Krefling.
1960. FACTORS IMPORTANT TO YELLOW BIRCH ESTABLISHMENT IN UPPER MICHIGAN. *Ecol.* 41: 18-28, illus.
- Hoyle, Merrill C.
1965. GROWTH OF YELLOW BIRCH IN A PODZOL SOIL. USDA Forest Serv. Res. Paper NE-38, 14 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.
- Leak, William B.
1968. BIRCH REGENERATION: A STOCHASTIC MODEL. USDA Forest Serv. Res. Note NE-85, 7 pp. NE. Forest Exp. Sta., Upper Darby, Pa.
- Leak, William B.
1969. STOCKING OF NORTHERN HARDWOOD REGENERATION BASED ON EXPONENTIAL DROP-OUT RATE. *Forestry Chron.* (accepted for publication).
- Logan, K. T.
1965. GROWTH OF TREE SEEDLINGS AS AFFECTED BY LIGHT INTENSITY. I. WHITE BIRCH, YELLOW BIRCH, SUGAR MAPLE, AND SILVER MAPLE. Canada Dep. Forestry Pub. 1121. 16 pp., illus.
- Marquis, David A. and John C. Bjorkbom.
1960. HOW MUCH SCARIFICATION FROM SUMMER LOGGING? USDA Forest Serv. NE. Forest Exp. Sta. Forest Res. Note 110. 3 pp., illus., Upper Darby, Pa.
- Marquis, David A., John C. Bjorkbom, and George Yelenosky.
1964. EFFECT OF SEEDBED CONDITION AND LIGHT EXPOSURE ON PAPER BIRCH REGENERATION. *J. Forestry* 62: 876-881, illus.

- Marquis, David A.
1965. CONTROLLING LIGHT IN SMALL CLEAR-CUTTINGS. USDA Forest Serv. Res. Paper NE-39, 16 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.
- Marquis, David A.
1966. GERMINATION AND GROWTH OF PAPER BIRCH AND YELLOW BIRCH ON SIMULATED STRIP CUTTINGS. USDA Forest Serv. Res. Paper NE-54, 19 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.
- Marquis, David A.
1967. SOIL MOISTURE - SOIL TEMPERATURE INTER-RELATIONSHIPS ON A SANDY-LOAM SOIL EXPOSED TO FULL SUNLIGHT. USDA Forest Serv. Res. Note NE164, 5 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.
- Marquis, David A., Dale S. Solomon, and John C. Bjorkbom.
1969. A SILVICULTURAL GUIDE FOR PAPER BIRCH IN THE NORTHEAST. USDA Forest Serv. Res. Paper NE-130, 47 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.
- Redmond, D. R., and Robena C. Robinson.
1954. VIABILITY AND GERMINATION IN YELLOW BIRCH. Forestry Chron. 30: 79-87.
- Sarvas, Risto.
1948. A RESEARCH ON THE REGENERATION OF BIRCH IN SOUTH FINLAND. Comm. Inst. For. Fern. 35(4). English summary 82-91.
- Sarvas, Risto.
1952. ON THE FLOWERING OF BIRCH AND THE QUALITY OF THE SEED CROP. Comm. Inst. For. Fern. 40(7): 35 pp.
- Shigo, Alex L., and George Yelenosky.
1963. FUNGUS AND INSECT INJURY TO YELLOW BIRCH SEEDS AND SEEDLINGS. USDA Forest Serv. Res. Paper NE-11, 11 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.
- Tubbs, Carl H.
1963. ROOT DEVELOPMENT OF YELLOW BIRCH IN HUMUS AND A SANDY LOAM. USDA Forest Serv. Res. Note LS-33, 2 pp., illus. Lake States Forest Exp. Sta., St. Paul, Minn.
- Winget, C. H., and T. T. Kozlowski.
1965. YELLOW BIRCH GERMINATION AND SEEDLING GROWTH. Forest Sci. 11: 386-392.