

NATURAL REGENERATION OF YELLOW BIRCH IN CANADA

by D. H. BURTON, H. W. ANDERSON, and L. F. RILEY. *The authors are respectively Supervisor of Forest Research and Research Scientist, Ontario Department of Lands and Forests, Maple, Ontario and Forestry Officer, Canada Department of Fisheries and Forestry, Sault Ste. Marie, Ontario.*

The Yellow Birch Resource

IN CANADA yellow birch populates a geographic range that extends from the Manitoba-Ontario border through southern Ontario and Quebec and eastwards throughout the Maritime Provinces and Newfoundland (fig. 1). The northern limit of its range corresponds closely with the 64°F. isotherm of the mean daily July temperature.

The important commercial stands of yellow birch forests are restricted to the southern portion of the Canadian Shield, extending up the St. Lawrence Valley to the Maritimes. In Ontario, the major concentrations occur in the vicinity of the Algoma, the Algonquin and

Haliburton Highlands. The southern boundary of commercial distribution is closely associated with the 1000-foot contour of elevation. Peculiar to this highland condition is a cooler temperature but increased precipitation, giving rise to a somewhat Maritime climate, which appears to favor yellow birch. In the same province, according to published statistics, yellow birch comprises about 7 percent of the total hardwood growing stock, and of this, 42 percent occurs in the Sault Ste. Marie Forest District (Algoma area) and 40 percent in the North Bay, Pembroke, and Parry Sound Forest Districts (Algonquin area) together (Dixon 1963).

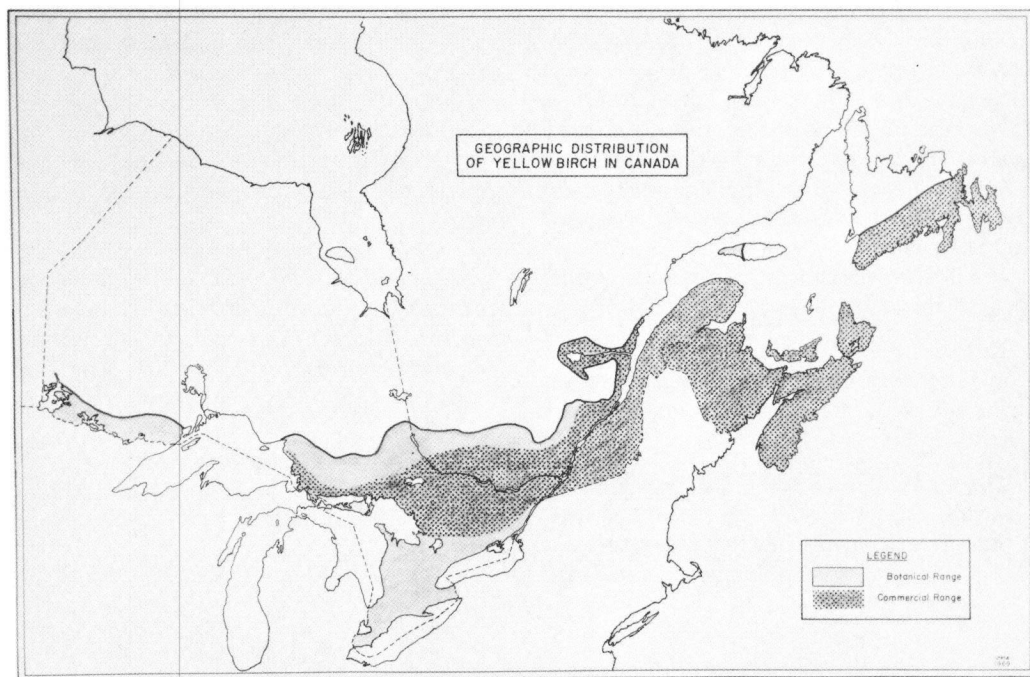


Figure 1.—Geographic distribution of yellow birch in Canada.

The species is utilized extensively in Ontario, where in 1965 yellow birch comprised 19 percent of the total hardwood cut from crown lands, some 20,000 M board feet coming from Sault Ste. Marie alone (*Brunelle 1967*). In terms of financial return, yellow birch provides 50 percent of the stumpage value received from all hardwoods cut, and this species accounted for 38 percent of the sawtimber and veneer depletion.

The heavy cutting pressure has continued more or less unabated over the last few decades, rising from 6 million cubic feet in 1957 to 9 million cubic feet in 1965 (*Anonymous 1967*). The increasing mill demands are now being filled with greater amounts of sugar maple, a species generally of poorer quality. In the last decade the use of sugar maple has doubled and now approaches yellow birch in gross volume cut. Similar pressures are apparent in Quebec, where the hardwood growing-stock volume appears to be higher than in Ontario.

The serious lack of young growing stock of yellow birch in the uncut and selectively cutover hardwood stands has been documented in regeneration surveys in Ontario (*Leslie 1931, Jarvis 1956, Hosie 1953*), Quebec (*Cunningham 1952, Winget 1968*) and the Maritimes (*Drinkwater 1957*). In addition to the lack of birch regeneration (1 to 4 inches d.b.h.), only 12 percent of the almost 4 billion cubic feet of yellow birch growing stock in Ontario is 4 to 9 inches d.b.h. As much as 97 percent of the cubic-foot volume in some areas is in trees over 100 years old.¹ Studies in mature stands of yellow birch indicate that the majority of veneer-quality trees are well over 200 years old.²

In Ontario two approaches have been taken to offset this important problem:

1. Large-scale regeneration procedures based upon research to secure birch growing stock for the market minimally some 60 years hence.
2. The application of techniques for growing quality hard maple to bear the brunt of the current pressure, pending the maturation of the birch regeneration that we are just beginning to obtain.

Ecological Framework

The center of dominance (ecologically speaking) of yellow birch spreads through

central Ontario and into southern Quebec (*Hills 1959, Rowe 1959*). The acid soils of the Precambrian Shield, combined with areas of higher precipitation, favor the birch association over the hard maple-beech type, which encroaches from the south, in the vicinity of Lakes Ontario and Huron (fig. 2). In the northern part of the birch range of dominance, a strong boreal influence is seen, where the birch type is relatively restricted to the somewhat drier uplands, especially the northerly aspects (fig. 2). Growth form is affected as a result of ecological pressure, in that birch growing in the Algoma highlands have shorter clear boles and smaller volumes per tree than trees in the Algonquin highlands, which is closer to the central portions of the birch zone (*Morawski and others 1958*). Conversely yellow birch, as it approaches its southern limit, tends to be restricted to areas having a higher water table.

Effects of glaciation have left much of the Canadian Shield area with a thin discontinuous mantle of till on the uplands, and deep water-laid deposits in the valleys and lower flats. In such areas excellent production of birch is found on the lower slopes, influenced by a telluric water table, and on the broad deep-soil drumlinoid ridges. Performance on the shallow-soil uplands is more variable and is related to many factors such as aspect, eco-climate, soil texture, humus development, etc. Extreme site variations occurring over short distances—the so-called fractured site complex—necessitate site-typing as a prerequisite for any serious attempt to obtain regeneration, establishment, and development of yellow birch.

Though regional differences in soils and climate occur east of Ontario, yellow birch appears to prefer a rather exacting ecological niche in Quebec (*Lemieux 1963*) and the Maritimes (*Drinkwater 1957*) in a somewhat similar order of magnitude.

Background Research

It has been shown by Redmond and Robinson (1954) that yellow birch seed contains

¹Cardwell, B. Personal communication, unpublished timber-inventory data, Ontario Dep. Lands and Forests, 1969.

²Duncan, J. M. THE ORIGIN OF YELLOW BIRCH IN TOLERANT HARDWOOD STANDS. Undergraduate thesis, Univ. New Brunswick, 1962.

a water-soluble germination inhibitor in the seed-coat, which is inactivated by exposure to light. This "chemical rain gage" prevents premature germination during cold weather when sugar maple seed is breaking dormancy. Light inactivation of the system occurs later in the spring when the very delicate birch germinant would be less prone to low-temperature hazards. These authors also note the lack of viability in certain years, which they attribute to weather effects on pollination: however, our observation at Swan Lake, Ontario, suggests that birch adheres very closely to a 3-year cycle (1950, 1953, 1956, 1960), with practically no seed produced intermediately, except

distress crops from low-vigor specimens. The bulk of the yellow birch seed falls after the cold weather of October sets in; it may be blown over the crusted snow for some distance, having been recorded on the snow-covered lakes as far as 1/4 mile from shore.

Linteau (1948) showed in a study of two seedbed conditions (mineral or litter) and three light conditions (open, partial, and closed) with artificially-seeded plots, that there is a negative effect of litter and low light level on the establishment of yellow birch reproduction. Summer logging by group selection in a good seed year was suggested as an alternative to the normal light selective logging.

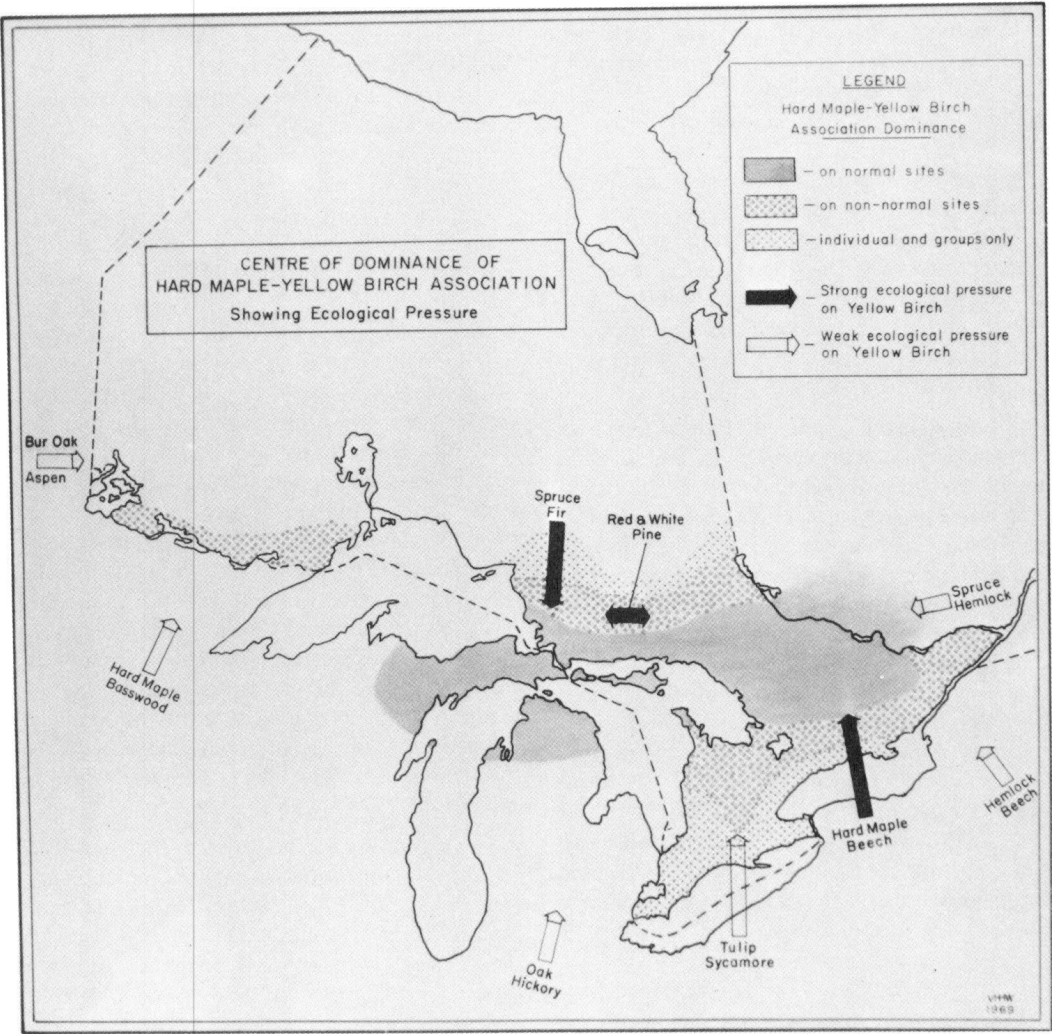


Figure 2.—Center of dominance of hard maple-yellow birch association, showing ecological pressure.

In 1950, a modified commercial cutting operation was initiated at Thurso, Quebec.³ Heavier than normal cutting (13-inch diameter limit) increased the birch stocking by 10 percent compared to light selective cutting, apparently because of the greater degree of ground disturbance and canopy opening. Stocking to sugar maple, a severe competitor under restricted light conditions, also increased, leaving the birch in a less than desirable condition for good development. Nevertheless, early results supported Linteau's previous conclusions.

Moist mineral soil enriched with considerable humus contributes to better survival and growth of yellow birch than either mineral soil or duff alone (*Jarvis 1957*). Redmond (1954) demonstrated much better root development in loam (ignition loss 7.64 percent oven-dry weight) than in sand (ignition loss 0.39 percent oven-dry weight). In 1957, Redmond noted that in mature hardwood stands heavy to birch, 80 percent of the feeding rootlets occurred in the humus layers, usually comprising the top 5 cm. of the soil profile. Larger roots occurring in the B horizon normally had their feeding roots in the upper organic layers. Deeper rootlet penetration commonly followed decomposing old root channels. Two-year-old leaf litter was also invaded by rootlets.

Wang (1965) compared seedbed moisture, texture, and canopy density in the Algoma region of Ontario with respect to the performance of 2-year-old natural birch regeneration. The mixed-texture seedbed consistently gave the best height growth regardless of canopy density or moisture regime. Duff tended to yield better growth at heavier canopy densities than mineral soil seedbeds, the reverse being true for open stands. In all of these cases, however, development was best on the freshest moisture regimes. There was also the suggestion that better growth occurred at lower canopy densities on moist areas than on drier sites. In the early stages of life, seedbed moisture may be more limiting to growth than light availability, at least at the northern limit of the species' range.

The Ontario government established, in 1950, a forest research reserve at Swan Lake in Algonquin Park. The land was to be used to study the factors that limit the establishment and development of yellow birch in central Ontario. Early work at the Algonquin Reserve was concentrated in undisturbed mature and overmature hardwood and mixed-wood stands of the area. From 1950 to 1957, a number of factors were studied, including seed supply, viability and dissemination, continuous determination of moisture, temperature and physical condition of various seedbed types, precipitation and vegetation phenology, and dynamics, all relative to yellow birch and hard maple survival and development.

A good birch seed year in 1950 at Algonquin provided material for a study of reproduction in undisturbed forest conditions. Viability of the seed was better than 40 percent, providing an opportunity for more than adequate stocking. A series of permanent sample plots was established, and a fixed representative population of new yellow birch germinants were staked, numbered, and mapped in the fall of 1951, so that specific seedling histories could be followed over time. Stocking and density estimates were sacrificed in favor of specific biological information relating to mortality. Three hundred yellow birch seedlings were tagged in September 1951. After one growing season, the marked seedlings were stratified according to their current leaf development. It was apparent that seedlings entering the winter in an advanced stage of development suffered far less first-winter kill (fig. 3). In fact, it was possible to separate survival rate in the sequential order of original leaf development; however, all seedlings were dead by 1961. From this early work, the major factors contributing to seedling death in a natural uncut forest were determined by continuous examinations throughout the snow-free periods (*Burton and Leslie 1952*).

High germination occurred in the spring of 1951 in uncut Algonquin stands, on the surface of the litter mat. These germinants died rapidly in great numbers primarily because their radicals could not penetrate the so-called "crust barrier" of snow-flattened maple leaves some 10 layers thick. Seed positioned between the layers of the litter mat also germinated. These died somewhat earlier than

³ Daubney, P. E. REPORT ON REGENERATION SURVEY ON TWO-YEAR-OLD CUTOVER AREAS. Unpublished report, Singer Manufacturing Co., Papineau, Quebec, 1952.

those on the surface because the delicate hypocotyls were unable to pierce the litter overburden.

The felt-like matting of hard maple litter is a major seedbed problem in south-central Ontario, where the associated species is predominantly hard maple and current litter breakdown is comparatively slow. This may not be a problem in other areas, including parts of southern Ontario, where there is rapid incorporation.

Maple leaves have a strong tendency to mat. This is because of their size and weak palmate venation as compared with beech, elm, and birch, which are pinnately veined and tend to curl upon drying.

Finally it was determined that the first-year height growth of the seedlings (1 to 2 inches) was not sufficient in the low light level of the uncut forest to withstand the overwinter flattening and smothering effects of the subsequent autumn leaf fall (Koroleff 1954).

In the spring of 1954, the sample plots used in the 1951 study were used to study regeneration occurring as a result of the heavy 1953 seed crops; and new germinants were staked over a variety of micro-environments. In this study, only cotyledonous seedlings were available, and thus no differential in leaf developments had yet occurred. However, it had been noticed that hypocotyls show a response in their color to the amount of light they received, so the seedling population was stratified and staked according to the degree of redness of the hypocotyl, ranging from red through pink and pink-white to green-white.

The survival rate could be segregated, sequentially in order of the four stem colors, redness indicating a better survival rate (fig. 4). The rapid fall of the red curve was due to a very small sample; the occurrence of *reds* was limited by the low light level. As before, extensive mortality occurred within a very few years.

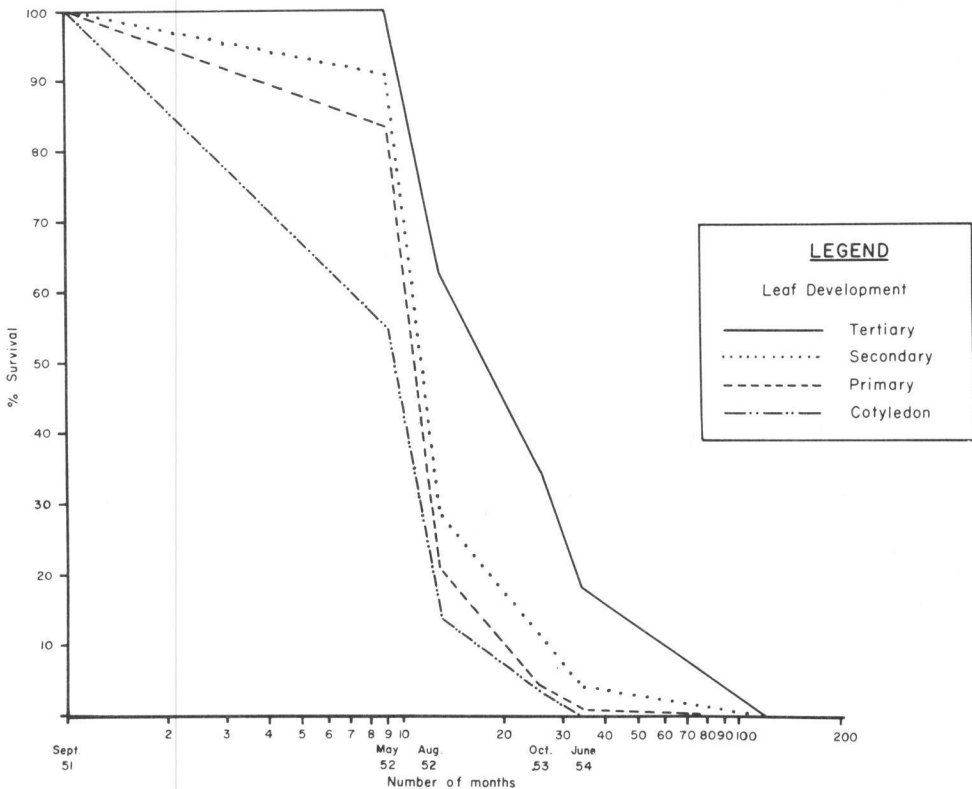


Figure 3.—Survival rate according to degree of leaf development of yellow birch germinants in an uncut forest. (Seed-year 1950.)

Hypocotyl colorations have been noted previously in new germinants of other tree species, especially conifers (*Bates 1925, Krugman 1956*), and the phenomenon has been associated with light (especially ultraviolet) in alpine plants (*Weaver and Clements 1938, Caldwell 1968*). Harvey (*1923*) suggested that they may have a protective action with the respect to insolation injury, since the red color would tend to reflect the destructive heat rays.

The red hypocotyl coloration may be a photomorphogenically produced vacuolar flavonoid pigment, dependent upon two basic radiant-energy systems for its formation. In such a mechanism, bright-level exposure to high-energy blue light at 470 nanometers establishes the prerequisites which, if followed

by low-energy radiation at 660 nanometers, will give rise to flavonoid compounds that are red in acid environments (anthocyanins). The low quantum red effect is mediated by the well-known phytochrome system (*Hendricks 1968*), and perhaps exerts its action by affecting the acetyl coA reactions of fat metabolism (*Butler and Downs 1960*) known to be precursors of part of the flavonoid system. The blue effect presumably affects hormone or enzyme activation through a cis-trans isomerism, such as with cinnamic acid and several other metaloblic regulators (*Zimmerman and Hitchcock 1939, Kauffman et al. 1968*). The coloration develops in situ within the cell and is an inherent characteristic of the species, although in some plants, such as wheat, coleoptile color is related to chromosome number (*Anonymous 1952*).

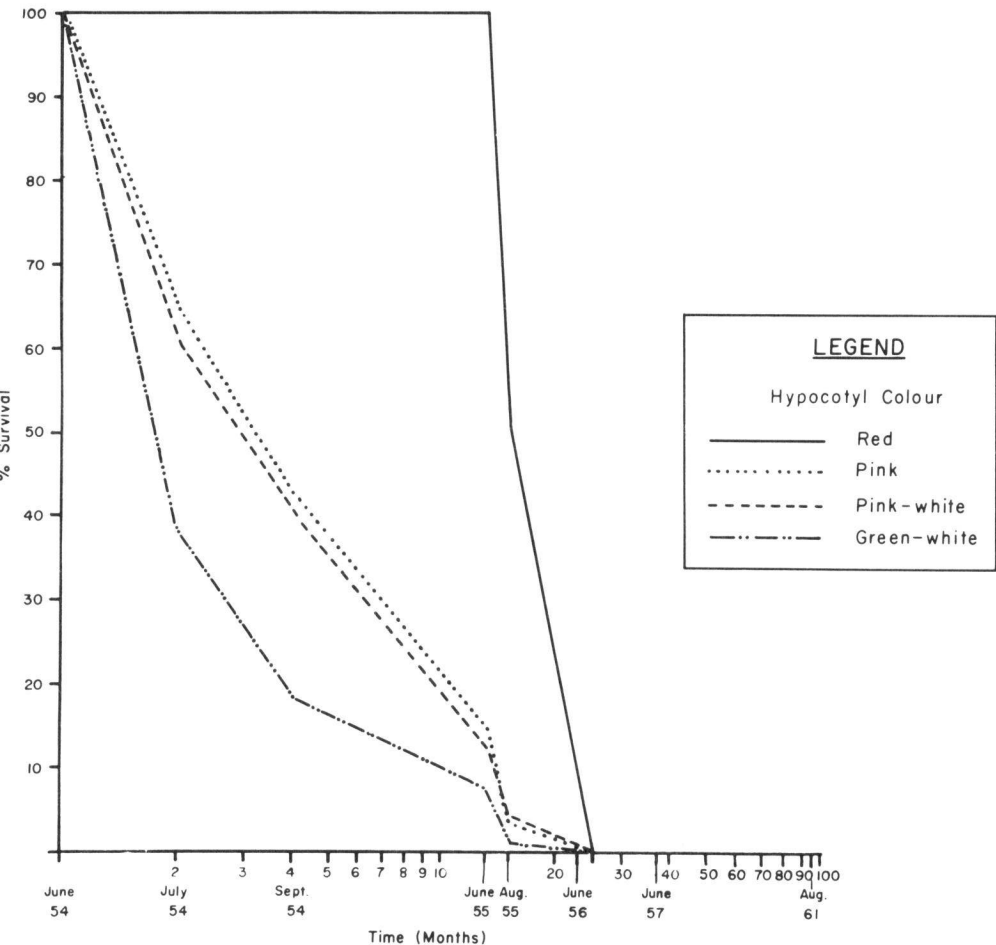


Figure 4.—Survival rate according to hypocotyl color of yellow birch germinants in an uncut forest. (Seed-year 1953.)

The variation in coloration, duplicating that found in the forest, has been produced by germinating birch seed under low light, then providing replicates with light exposures (cool white fluorescents plus incandescents, 16-hour photoperiod) of from 2,000 to 35 foot-candles on a logarithmic scale in a growth chamber. Coloration is well developed in 3 days. After 10 days, primary leaf development and root length and form are related to light treatment and thus to hypocotyl color. The color pattern that can be easily recognized in new germinants is indicative of the light budget of the seedbed location and reflects the potential degree of fibrous root development and height growth of the seedling in its critical early life. The similarity of figures 3 and 4 would support this finding in terms of first-year survival. The 35 and 60-foot candle light levels used in the growth chamber approximate, in terms of intensity, the light levels of uncut hardwood forest.

In terms of relative occurrence according to stand density, it can be shown that only about 10 percent of the seedlings are red under fully stocked uncut stands, but that 59 percent of the seedlings are red under selectively cut stands, 78 percent are red in small patch cuttings (less than 0.05 acres) and 95 percent are red in large patch cuttings (0.05 to 0.19 acres).

Experimental Regeneration Systems

The findings of the early studies allowed the prescription of cultural stand treatments designed to overcome the limiting factors; and the bumper seed crop of 1953 was made to coincide with two separate comprehensive cutting experiments (*Burton 1956, Jarvis 1957*).

The Canada Department of Forestry established a study in the Haliburton Highlands in forest where a somewhat heavier-than-normal cut was taken out (about 3,000 board feet/acre) due to the general high quality of maple. Concurrent purposeful ground scarification, using tractors with straight blades, and girdling of culls to reduce crown canopy to about 40 percent, were further treatments. Control areas were not scarified, and crown canopies had normal cutover closure. On the basis of subsequent regeneration cruises, using permanent transects, excellent results were achieved on the treatment areas with yellow birch stocking of 66 percent

and densities of 4,800 seedlings per acre existing after 10 years. Control areas had less than half the stocking and density values, although some ingrowth from subsequent seed years has probably been included in these figures.

In the same year (1953) at the Algonquin Reserve a different approach was taken, with differing results. A light "normal" selective cut (2,000 board feet/acre) was made, and incidental scarification was accomplished by skidding tractor treads (no blade). Somewhat heavier-than-normal ground disturbance was obtained in the vicinity of cut trees by having separate skid trails located for each log from a given tree. Around the cut stumps, with their areas of disturbed litter, additional trees were felled to produce patch cuttings of different sizes. The purpose was to disturb the litter mat, to reduce subsequent leaf fall, and to supply more light to the seedbed than would normally be available in a cutover. Normal cutover conditions prevailed between the patches.

An excellent catch of germinants was obtained. A selected population of these was staked according to stem color on each patch and normal cutover area for survival and growth studies. In both the Haliburton and Algonquin experiments, a considerable number of seedlings reached a minimum height of 5 inches the first year. In contrast to the Haliburton study, however, there was total mortality of the thousands of staked birch seedlings at Algonquin in both patch cuttings and normal cutover by 1961.

This mortality was attributed to the unusually high resident deer population in Algonquin Park, where deer are protected by law. Surveys showed that 10 to 15 deer per square mile inhabit the area in summer; this exceeds the carrying capacity of the land, if overbrowsing is to be avoided.⁴ In addition, incidences of clipping by hares were observed in 1955-57 during a population peak of these animals. Continuous summer deer browsing in July and late August over a 6-year period effectively eliminated yellow birch regeneration. In retrospect, it is probable that the patch cutting, complete with concentrated tree-tops, attracted the deer to the openings and subsequently led to browsing of seedlings for food.

From a sample of 1,000 staked seedlings over a 3-year period (1955-57), slightly more

than 95 percent of the yellow birch in the patches that attained a minimum height of 6 inches were browsed at least once, and most of them two or three times.

As with the companion study in uncut stands, hypocotyl color proved a good indication of survival in both patch cutting and normal cutting (fig. 5). Green-white seedlings have a low survival rate; and after two growing seasons 74 percent of the seedlings growing in patch cutting that had attained at least 6 inches of height were pink-or red-stemmed. These favored seedlings were the first to be browsed by deer. Deer browsing killed some seedlings directly, but more frequently height was reduced to about 4 inches or less, which places a seedling in a position to be smothered by leaf fall or killed by suppression from less palatable vegetative competitors.

The Haliburton area, in contrast, was subjected to fairly heavy deer hunting pressure.

Though 79 percent of the quadrats showed some incidence of browsing, large numbers of seedlings escaped injury and developed uninhibited. Deer exclosures established at Swan Lake in 1956, after 21½ years of browsing⁴ allow comparison of the two studies. The reduced browsing and slightly better sites are reflected in the better Haliburton height growth, where 20 feet is an average dominant height after 10 years (*Wang 1968*). The heavier browsing conditions are clearly evident in the average height of the browse line on the two areas (fig. 6).

The extreme importance of animal populations was emphasized in an after-cutting scarification comparison trial established in

⁴ Stephenson, A. B., and R. L. Hepburn. DEER AND FOREST REGENERATION, ALGONQUIN PARK. Unpublished report, Ontario Dep. Lands and Forests, 1958.

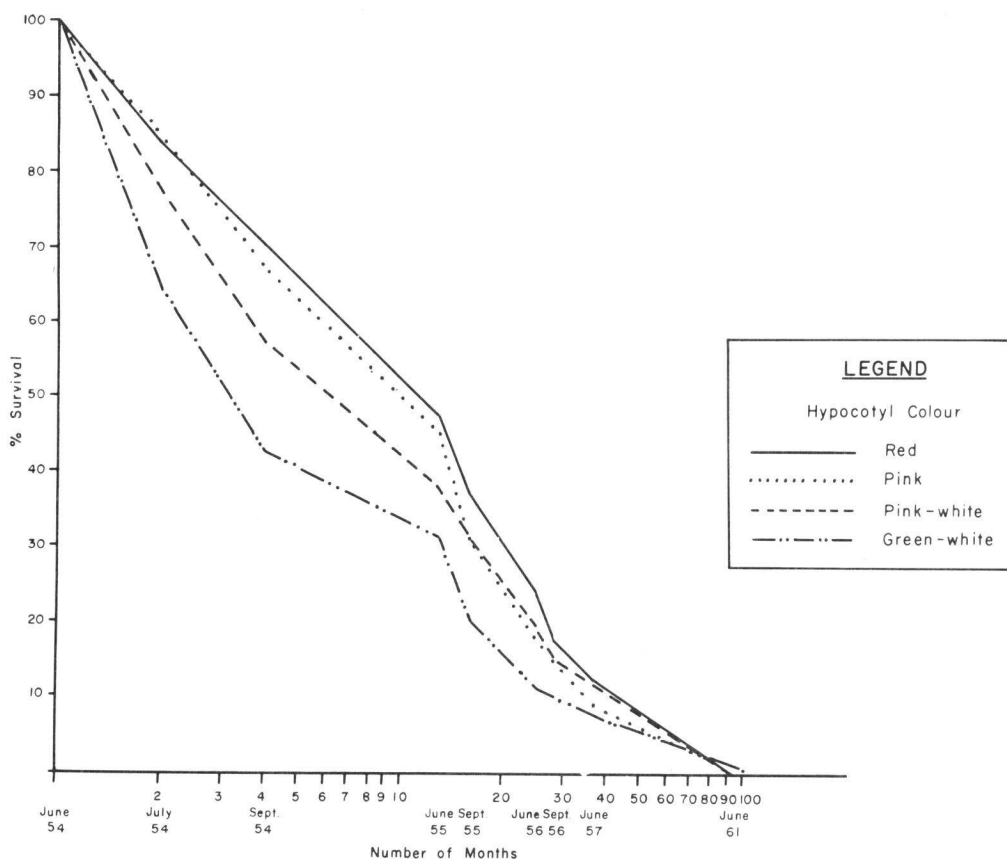


Figure 5.—Survival rate according to hypocotyl color of yellow birch germinants in a patch-cut area (cut in seed-year 1953.)

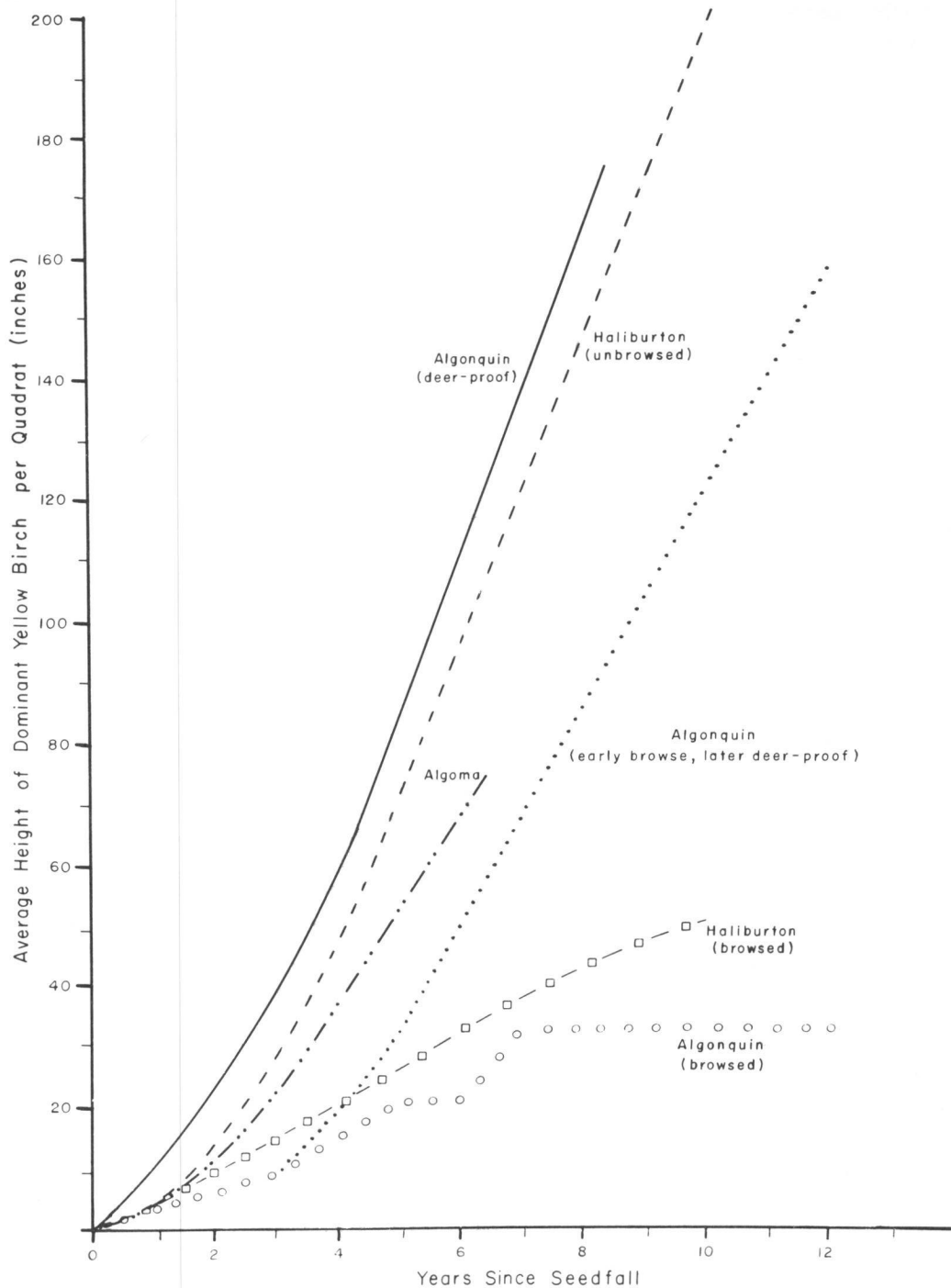


Figure 6.—Height growth of yellow birch obtained in several regeneration trials.

Haliburton in 1955, just before the peak of the hare population cycle (Fayle 1961). Clipping by hares destroyed the birch regeneration after an excellent catch of germinants. This problem is without comparable solution unless the culinary habits of Canadians can be changed to a preference for lagomorph stew instead of venison.

The total exclusion of deer in the Algonquin study by fencing resulted in an interesting shift in successional trend. Whereas normal light selective logging combined with an unrestricted deer herd invariably results in a predominantly maple ingrowth, heavier cutting combined with complete exclusion of deer allowed invading intolerant species, such as white birch, willow, aspen, and pin cherry, as well as yellow birch, to become established. This was perhaps more noticeable on the moister and richer sites, especially in combination with large crown openings. These encroaching species usually outgrew both yellow birch and hard maple, especially the latter.

Disease killed a number of seedlings on regeneration study plots. In 1954 and 1955, dieback and cankering affected many 2-year-old yellow birch seedlings growing in the experimental patches, often in the more exposed locations. Culture isolations yielded *Phomopsis* spp. in most cases, organisms similar to those that had been found infecting yellow birch showing birch dieback symptoms (Hansbrough 1952, Redmond 1952).

This fungus was shown to be moderately pathogenic upon inoculation and could cause mortality in yellow birch germinants and young seedlings. Infection in vigorous older stems was accomplished only through injuries, while trees under physiological stress were infected by topical application without wounding (Horner 1952). In 1960, sapling wilting, dieback, and cankering associated with *Phomopsis* spp. were noticeable on yellow birch, often on trees injured by browsing or early fall frost (Raymond 1960). The disease probably accounted for a considerable part of the mortality in the experimental patch cutting, the condition being aggravated by the infection courts established by the browsing and by the severe summer drought of 1955. There is some indication that high densities of seedlings, in conjunction with rapidly developing root systems and concomitant root competition, may promote development of the disease.

Early stem differentiation into positions of dominance would seem to reduce the severity of the disease due to its effect in reducing density and thus avoiding the prevalence of low-vigor stock.

Operational Regeneration Systems

At the completion in 1956 of the first phase of the Algonquin and Haliburton studies and as a direct result of them, the Ontario Department of Lands and Forests initiated large-scale scarification procedures throughout the commercial range of yellow birch in Ontario (some 5,000 acres in 1967).

A variety of machines and scuffer devices was employed, partly on pilot-scale trials to determine their effectiveness. In addition to seedbed treatment, stands are being opened up to a considerably greater extent than in the past. Precutting and concurrent scarification has been carried out, but a great amount of effort has been put forth on after-cutting scarification, to rehabilitate degraded stands. Scarification techniques are designed to destroy the litter barrier, root out advanced growth to some degree, and prepare a receptive environment for germination, establishment, and growth of the more valuable commercial species.

In the operational trials, consideration was given to obtaining a suitable mix of seedbed components, the importance of which has already been mentioned.

Scarification was tested in the Haliburton Region on more than 1,000 acres, using various sizes of bulldozers equipped with blades. TD-14 and D-6 machines were powerful enough to root out advance growth and wind-falls as well as scarify the ground. Additional cutting was done to make patches 1/10 to 1/3 acre in size. In some places, the blades dug too deep, exposing the A₂ horizon. Though this ground condition afforded a good catch of birch, subsequent survival and growth were very poor.

By a stocking standard of 10 birch per milacre as satisfactorily stocked, three growing seasons after treatment there was 88 percent stocking on scarified samples in patches, 26 percent stocked in normal heavy cutovers, but 0 percent in closed forest.⁵ At this time, 50

⁵ Sinclair, G. A. EVALUATION OF CULTURAL TREATMENTS. Unpublished report, Ontario Dep. Lands and Forests, 1959.

percent of the seedlings were taller than 24 inches in the patches, but only 26 percent achieved this height in the normal cutting. On unscarified ground, 30-percent stocking occurred in the patches, with no stocking in uncut forest.

Similar operations carried out in northern Algonquin Park, near Kiosk, had limited success due to the deer population, although excellent catches were initially recorded. This trial was one of the first attempts at scarifying ground in early winter. The litter mat was frozen and the bulldozer blade easily peeled it back, exposing the humus and duff layers. This was one of the most economical blade-scarification jobs ever carried out, mainly due to the litter condition. The area overwintered a deer population of approximately 60 deer per square mile; however, the very extensive cutting operation was partitioned with purposely manufactured "top-jackpots" which acted as natural deer exclosures to some degree, and which tended to interrupt the natural browse continuum. The deer population dropped to about 15 per square mile the following winter, and there was almost negligible browse damage on the birch seedling stock.⁴

Some of the most extensive rehabilitation and testing work in the Province has been carried out in the Algoma Region by the Sault Ste. Marie District staff. In studies similar to the Haliburton trial, blade scarification was found to give a higher initial density of birch compared with that obtained by using a mounted rake in place of a blade, but average dominant height was substantially better on the rake-prepared sites.⁶ The blade removed more of the competing vegetation. Shelterwood systems (some residual stems peripheral to patches $\frac{1}{3}$ acre or less) and clearcut strips were tested. Optimum strip width was 1 chain, and length (up to 440 feet) had little effect on performance. Birch stems grew somewhat better near the strip center (edge effect), but overall growth rate was similar in strip and patch systems. Mortality on patches was only half that in strips. Aspect had an influence in the strip method, the NW-SE orientation showing about 30 percent better density and average height after 5 years than strips oriented in a NE-SW direction. Birch consistently outperformed maple, perhaps in part because of the

negligible deer browsing. Some new germination occurred 2 and 3 years after seedfall; however, the seedbed had completely deteriorated within 5 years.

One study showed that 2 years after scarification (where there was about 40 percent ground coverage) and strip canopy reduction, 86 to 99 percent of the quadrats were stocked (10+ seedlings) to yellow birch, and that 35 to 48 percent of the quadrats had seedlings in a free-to-grow condition.⁷ After eight growing seasons, average dominant height was 6.39 feet, with 32 percent of the plots stocked to dominant yellow birch (fig. 6).

Rear-mounted, hydraulically-operated scarifiers such as disc- and fire-plows are suitable for site preparation only on level terrain. Better success on steep slopes or very rocky ground was obtained with anchor chain tractor-pad drag units. The fluid motion of a chain allows it to override rocks, stumps and slash and facilitates excellent mixing of mineral soil and humus. The degree of disturbance can be modified by choice of three weights (15-, 22-, or 32-pound links). Gross cost per chain-treated acre is around \$12, and net coverage varies from 20 to 40 percent. Winch-equipped tractors are recommended and ripper-cleat attachments facilitate the concurrent reduction of advance growth on the scarification corridor.

Auld and Graham⁸ point-sampled scarified strips made by rock rake, straight blade, and blade with Young's teeth to compare organic contents of the upper 2 inches of seedbed as a result of treatment. Ignition loss, expressed as a percentage of oven-dry weight, was used as a measure of organic content. Considerable variation was found both within and between treatments, ranging from about 2 percent to 50 percent. The degree of humus incorporation was influenced in part by the land physiography, very low values being associated with areas of ponded sand with a high water table. Upland areas generally

⁶ Graham, H. D. FIVE YEARS OF TESTS ON SEEDBED PREPARATION. Unpublished report, Ontario Dep. Lands and Forests, 1962.

⁷ Graham, H. D. YELLOW BIRCH REGENERATION SURVEY. Unpublished report, Ontario Dep. Lands and Forests, 1958.

⁸ Auld, J. M., and H. D. Graham. SOIL SURVEY OF AREAS MECHANICALLY SCARIFIED FOR YELLOW BIRCH. Unpublished report, Ontario Dep. Lands and Forests, 1967.

showed values averaging around 15 to 20 percent organic matter. No significant differences could be demonstrated between methods of treatment (95 percent confidence limit). No edge effect was found in sampling across the width of strips. These latter figures compare favorably with those given by Redmond (1954) for loam soil, which promoted good fibrous root development of yellow birch seedlings.

Riley⁹, in a study of incidental ingrowth of birch after site preparation for planting in Algoma, noted that rear-mounted drums produced 30-percent scarification of the mixed type, and a V-blade produced 20 percent, while an angle blade developed only 1 percent mixed. This latter figure, however, emphasizes that dependence for satisfactory site preparation lies entirely with the skill of the operator when front-end scarifiers are used.

A cost analysis, comparing two degrees of scarification, one in which only the best yellow birch sites were scarified and another in which all possible sites were prepared (dozer blade), showed average cost per net acre treated as \$8.74 and \$20.13 respectively.⁹ Relative birch stocking after 7 years was 64 percent (3,300 stems per acre) compared with 81 percent (5,100 stems per acre). By normalizing the degree of scarification to 60 percent, the estimated site-preparation cost per thousand trees established is about the same (\$3.32 vs. \$3.43).

Though after-cutting scarification for rehabilitation of degenerated cutover is important, it would seem desirable to accomplish restocking procedures coincidentally with the cutting operation. Recently the use of prescribed fire has shown much promise in terms of application, cost, and effectiveness (Sloane 1960; Burton and Sloane 1958). Autumn application of fire reduced seedling density (mainly maple) from 160,000 to a level of 18,000 per acre in an old-growth hardwood stand. It is estimated that almost all of the current maple seed crop had fallen before the burn, and was therefore consumed by it (Sinclair 1962). Single fall burns do not drastically reduce the number of sapling maple, although basal scarring and sprouting are apparent (Holowacz 1960). No significant changes in microbial numbers, soil pH, or the levels of available phosphorus, potassium, calcium, or magnesium were found.¹⁰

Spring burning, though somewhat more difficult to effect, usually has a higher killing power with respect to small saplings (Sykes 1964). In fact, three consecutive spring fires may kill up to 55 percent of all trees in the diameter range of 0.6 to 4.5 inches. A single fall fire primarily removes only the current leaf fall unless a dry autumn has allowed the previous litter barrier to dry out. However, that layer is in the initial stages of decomposition at this time, and by the spring after the burn it will not offer the extreme obstacle to newly germinating seed as it did the previous spring. From experience gained in several different trials, it is believed that the treatment can be done at an approximate cost of \$1 per acre.

An interesting point regarding seedbed texture after burning is that light fall fires seem to stimulate the growth of *Erythronium* (dog's-tooth violet) in the early spring, which have the faculty of "plowing" the litter or duff as they emerge from the soil, a sort of natural disturbance.

Current Research

Two regeneration experiments are now under way. At Valcartier, Quebec, an experimental patch cutting with scarification and hand-seeding was initiated in 1960. Four-year results indicate that patch size should be limited to 1/10 acre on south slopes to reduce temperature extremes and desiccation (Hatcher 1966). Also, it was shown that current leaf fall is minimal on the larger patches, and thus summer treatment might be possible on such areas. Patches less than 1/10 acre in size close their canopy rapidly. The most efficient size, therefore, would perhaps be in the neighborhood of 1/5 acre on normal sites. Loosened humus seedbeds appeared to give good results.

In 1960, a good birch seed year, a regeneration demonstration was established at Swan Lake Reserve. A 10-acre block of old-growth timber growing on a drumlinoid ridge was fenced to exclude deer. It was logged in early fall, using a partial cutting technique

⁹ Riley, L. F. A STUDY OF YELLOW BIRCH REGENERATION UNDER VARIOUS SEEDBED CONDITIONS AND TREATMENTS. Unpublished report, Can. Dep. Fisheries and Forestry, Ontario, 1968.

¹⁰ Raymond, F. L. SOIL SAMPLING AFTER PRESCRIBED FIRES. Unpublished report, Can. Dep. Agr. Forest Pathol. Lab., Ontario, 1960.

and taking the poorer trees. Skidding was done with a crawler-type vehicle, which provided some scarification, and skid trails were laid out to provide maximum ground coverage without being inefficient. Additional scarification was carried out with a drag-type scuffer and one-half the block was burned later in the fall. The logging operation amounted to a heavy improvement cutting, and resulted in a variety of residual densities from essentially uncut forest through to large open patches.

Quadrats were laid out in burned and unburned conditions and populations of yellow birch and/or hard maple germinants were permanently staked in 1961. An excellent catch of both species was obtained.

Survival, 33 percent after 8 years, was facilitated by the complete exclusion of deer. Quadrats had from 0 percent to 63 percent actual survival (fig. 7). Average height of the six tallest birch per plot after 8 years decreased as the residual point density (prism count) about the plot increased (fig. 8).

Good correlation exists between residual stocking and vigor, with some increase in variance occurring at the open end due to important azimuth effects of horizontal structure variation. Anderson (1964) also found that, for 2-year-old yellow birch, best height growth was related to lowest canopy densities.

Hard maple on the burned plots is developing more slowly than on unburned sites, for a given stand density (fig. 9). Both conditions, however, produce considerably less growth for maple than for birch. Little birch stocking was found on unburned soil, but those seedlings that survived in that condition performed as well as those on burned soil. The favorable maple development on the unburned seedbed may reflect a preference of the species for the natural maple environment. On the other hand, the fact that the poorer maple were always in mixture with yellow birch might suggest that some biological antagonism exists between the two species.

After the establishment period of 3 years or so, yellow birch should maintain about 3

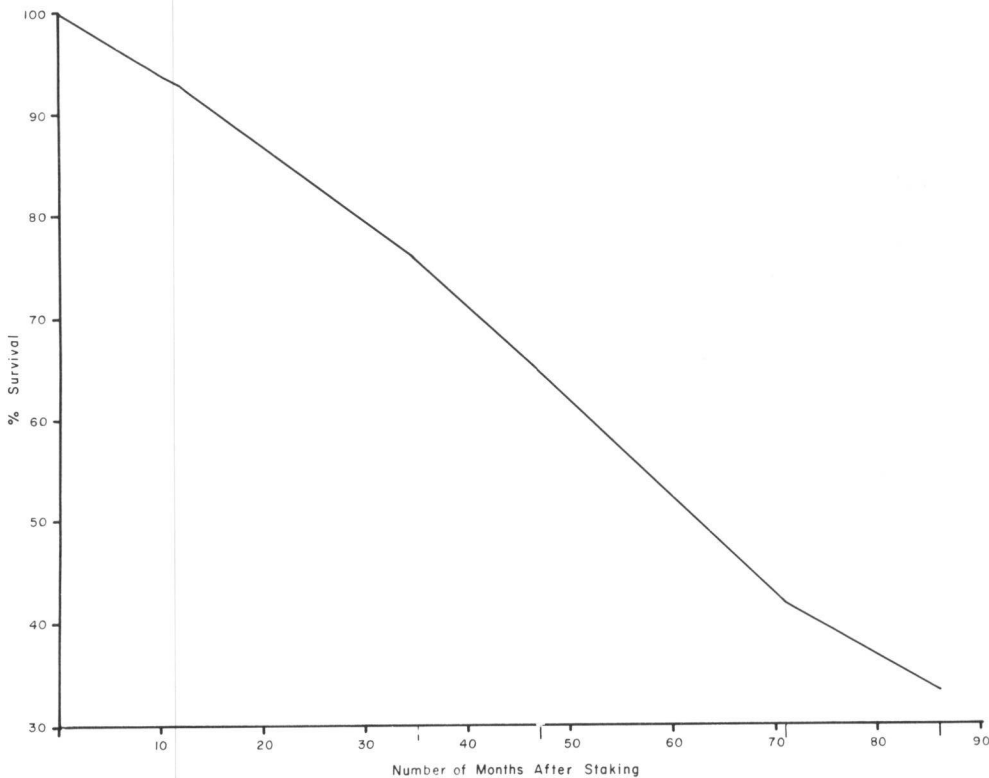


Figure 7.—Survival rate of yellow birch germinated in 1961, averaged over a range of stand densities. (Swan Lake drumlin.)

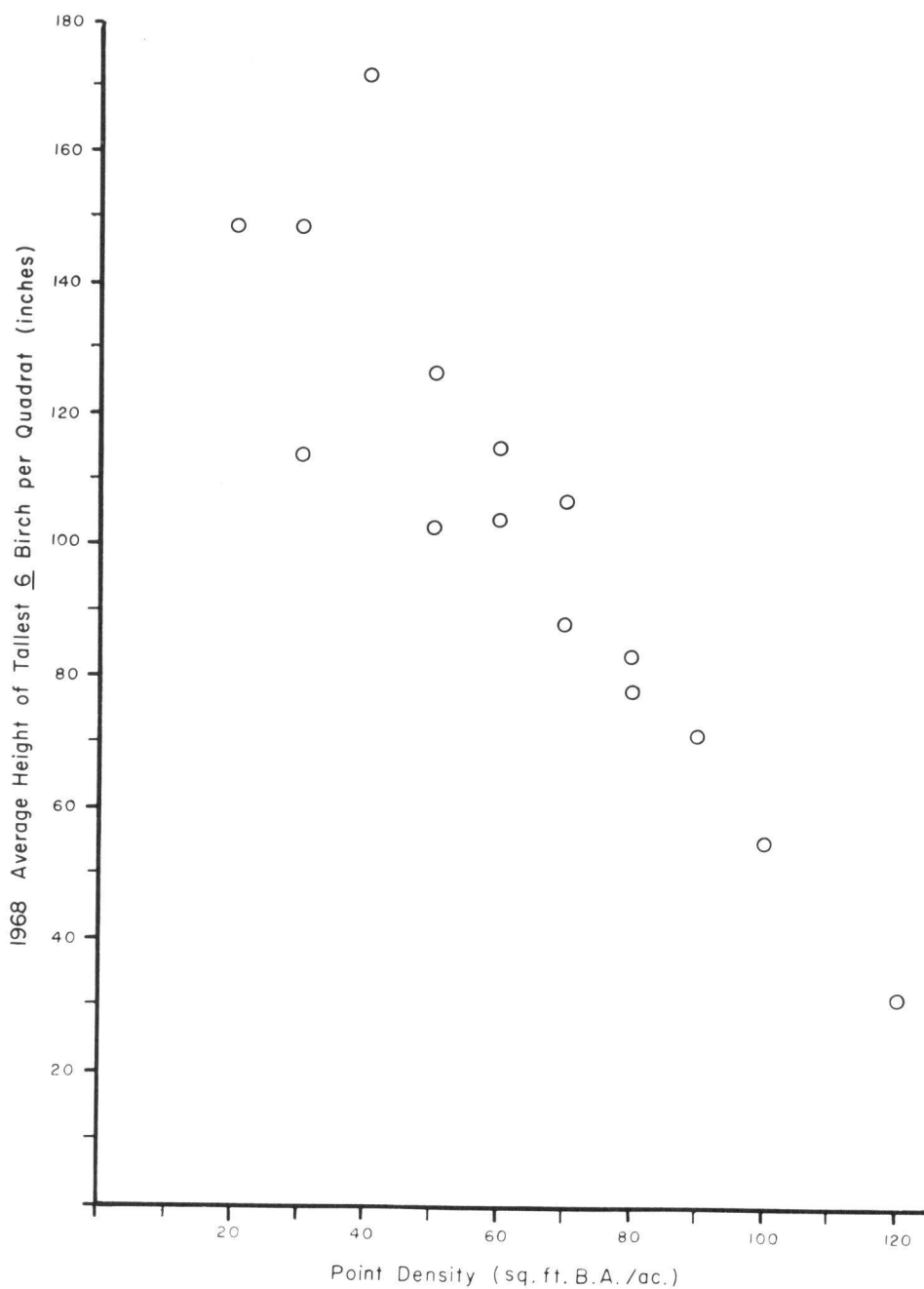


Figure 8.—Relationship of height of dominant yellow birch seedlings to stand density eight growing seasons after germination. (Swan Lake drumlin.)

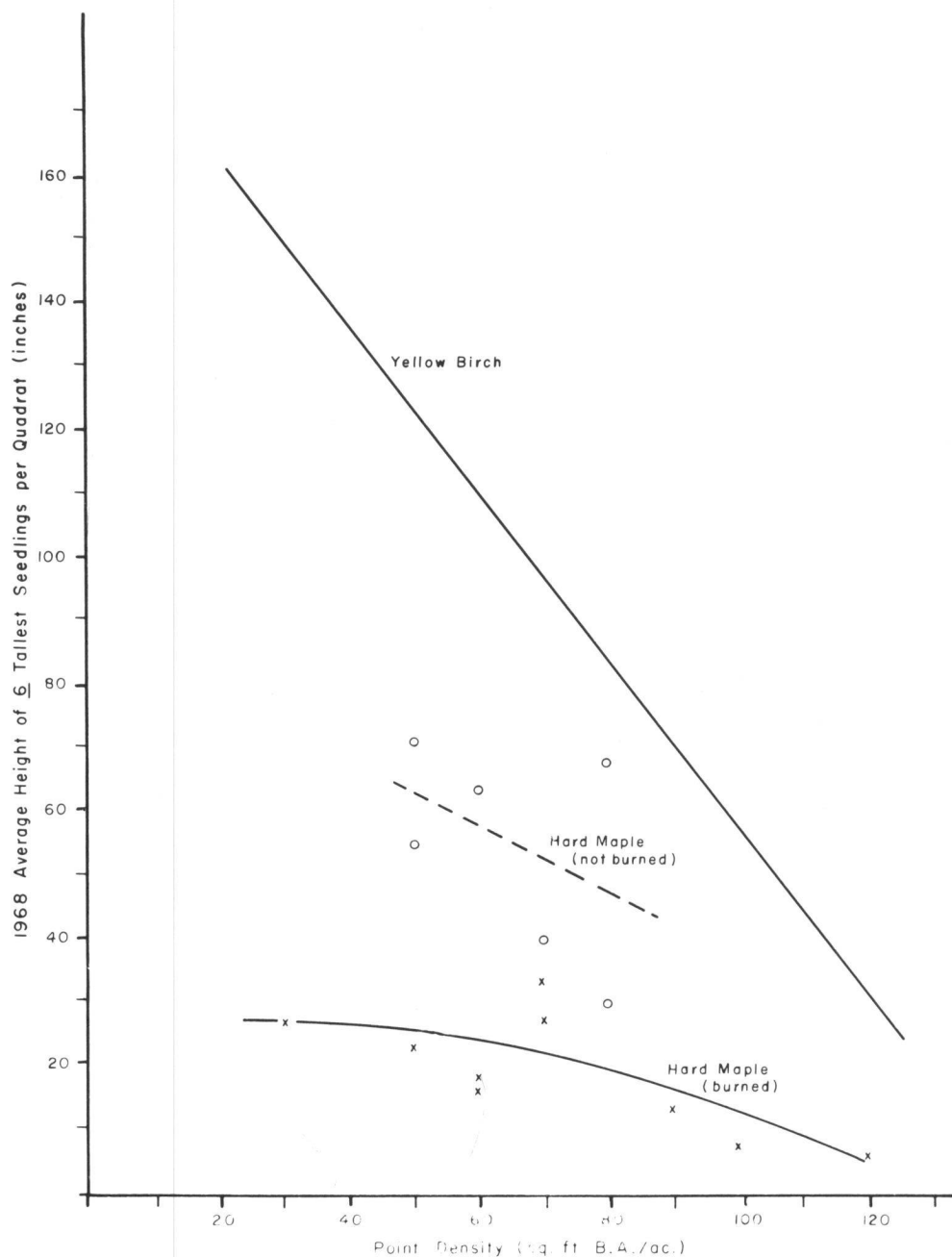


Figure 9.—Relationship of height of dominant hard maple seedlings to stand density eight growing seasons after germination, according to seedbed treatment. (Swan Lake drumlin.)

feet of terminal growth per year. Height ranking of individuals varies considerably from year to year in a given plot: the tallest seedling this year was not necessarily the tallest last year, nor may it be next year. Some minor tip-killing by *Phomopsis* (or the like) is fairly prevalent each year, and this may explain the fluctuation. Generally persistent dominant trees cannot be accurately chosen for the first 4 years after germination, and indeed there is doubt in some plots after even 8 years. However, most plots showing good vigor have at least a consistent group of three seedlings that dominate the plot.

Plots showing the best birch growth also show the highest birch mortality. Apparently the emergence of dominance is associated with trees that develop the best root system and that, as the root pattern of these trees develop as a result of better competitive position, root competition causes the smaller trees to succumb. This mortality, however, helps the dominants to more efficiently utilize the surrounding soil. A consistently rapid height growth in vigorous birch at low canopy densities would seem to be made at the expense of survival. At higher canopy densities, mortality is less extreme but height growth is not consistent, tending to slow down after 4 years. Lack of height or root differential in the quadrat population seems to cause overall lowering of vigor, rather than an abrupt polarizing effect on survival.

Such is the paradox with yellow birch. Initially we are hoping for a good seedling catch, yet later we would prefer crown differentiation at the expense of survival. Hand-seeding studies have demonstrated also the adverse effects of overstocking in yellow birch, in terms of development and disease occurrence.

Yellow birch possesses well developed, extensive lateral rooting and less intensive central rooting than maple (Fayle 1965), although birch roots may also penetrate deeply under favorable soil conditions (for example, old root channels).

The improved light conditions affect root development more than height development after 3½ years (fig. 10). Lateral roots extend radially as far as the tree is tall, and it is reasonable to assume that intense root competition exists in such plots. This extensive root development probably gives birch an ad-

vantage over maple in terms of initial establishment under low canopy densities.

Logan (1965) considered the effect of light intensity on root and top development of yellow birch and hard maple. Yellow birch showed best height growth in 25 to 45 percent light while shoot and foliage dry weights were maximized at 45 to 100 percent light. Sugar maple tended to perform less selectively over a wider and lower range of light conditions. In terms of root development (dry weight) yellow birch produced best on 45 to 100 percent light, whereas hard maple showed absolutely no preference in this respect. Our observations support Logan's findings with respect to both top and root development, although full sunlight was not tested in our work (fig. 10).

In at least two studies,^{5,9} average height growth of yellow birch seedlings for a given canopy density (open to partially closed) has been better on the few seedlings that become established through cracks, holes, or vegetation plowing on unscarified ground than on prepared seedbeds (including mixed conditions). This suggests that for yellow birch as well as for maple, as discussed previously, a natural rhizosphere is best for growth, provided initial establishment is possible. However, this observation is based on limited data, and further study is required on the fundamental requirements of root environment for young seedlings. Light-intensity measurements made in 1964 (fourth growing season), using a Weston illuminometer, showed maximal values of about 40 percent full sunlight, corresponding to the lowest residual stand densities. Poor correlation was noted at that time between height and light; however, after eight growing seasons, 8-year-growth shows a fair degree of correlation with fourth-year light intensity.

Eighth-year mortality also showed some degree of correlation, as one would expect. Maple, on the other hand, showed an overall lack of correlation of height or mortality on light intensity. This improved fit of values after 8 years with the birch is further evidence of the initial juggling that occurs for the first 4 years or so.

Height growth of yellow birch depends to a large degree on current photosynthate, and increases in light intensities up to 40 percent of full sunlight. At the molecular level, the

saturation point in terms of energy utilization at the metabolic sink usually occurs at about 20 percent full light. Other factors limit saturation, which are also illustrated by the well-known Blackman effect. However, the extra light energy beyond 20 percent presumably aids the shaded lower leaves to approach saturation, which would not occur under optimal light levels for the top leaves only.

The limit imposed upon the size of opening desired may be affected more by the chance of invasion by pioneer species than by growth considerations. Riley⁹ demonstrated also that

yellow birch tends to dominate all quadrats at canopy densities of 40 percent but that the chance of dominance decreases as canopy density increases. To obtain optimum light condition for growth, it is necessary to consider patch size, stocking density, light intensity, or canopy density; and perhaps studies should be undertaken to relate these factors to one another, all in relation to performance of yellow birch. There seems to be little problem in getting yellow birch to regenerate now; the current need is for information to help this regeneration to grow into veneer-quality trees.

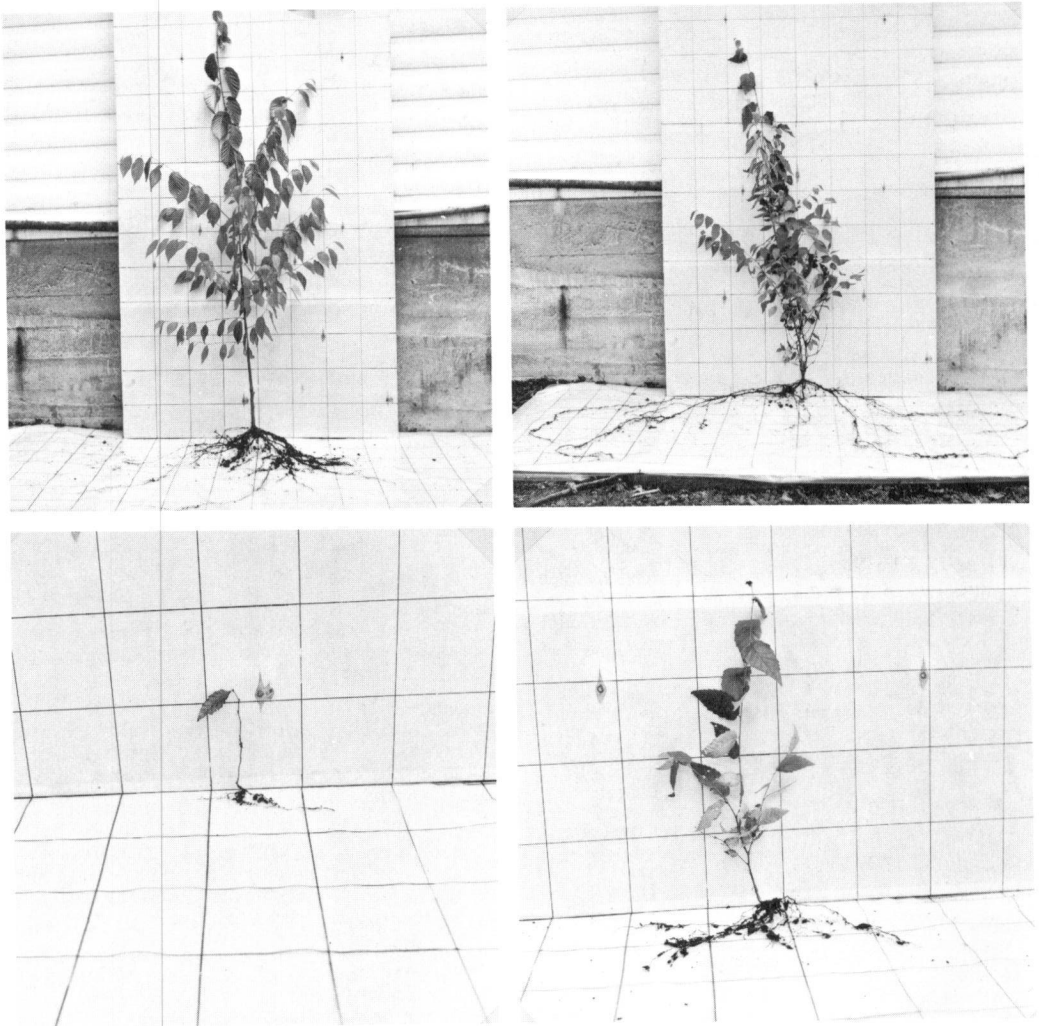


Figure 10.—Yellow birch seedlings excavated during their fourth growing season, representing overwood densities (reading clockwise from upper left) of 30, 60, 90, and 120 square feet of basal area per acre. Grid squares are 6 inches. Note especially root development.

Literature Cited

- Anonymous.
1952. MUNSELL COLOR CHARTS FOR PLANT TISSUES. Munsell Color Co., Inc., Baltimore, Md.
- Anonymous.
1967. A STATISTICAL REFERENCE OF LANDS AND FORESTS ADMINISTRATION 1967. Ontario Dep. Lands and Forests, Operations Br. 215 pp. Toronto, Ont.
- Anderson, M. L.
1964. HEIGHT GROWTH OF YELLOW BIRCH SEEDLINGS UNDER VARIOUS CANOPY DENSITIES. Can. Dep. Forestry mimeo. report 64-0-2. 9 pp.
- Bates, C. G.
1925. A KEY TO THE IDENTIFICATION OF SOME CONIFEROUS SEEDLINGS. J. Forestry. 23: 278-281.
- Brunelle, R.
1967. ANNUAL REPORT OF THE MINISTER OF LANDS AND FORESTS, PROVINCE OF ONTARIO FOR THE FISCAL YEAR ENDING MARCH 31, 1967. 124 pp. Ontario Dep. Lands and Forests, Toronto, Ont.
- Burton, D. H.
1956. YELLOW BIRCH REGENERATION. Sylva 12: 17-21.
- Burton, D. H., and A. P. Leslie.
1952. SOME SILVICAL CHARACTERISTICS OF YELLOW BIRCH. Symp. Birch Dieback Proc.: 57-58, Ottawa, Ont.
- Burton, D. H. and N. H. Sloane.
1958. PROGRESS REPORT ON PRESCRIBED BURNING IN THE HARD MAPLE - YELLOW BIRCH COVER TYPE IN ONTARIO. Ontario Dep. Lands and Forests Res. Br. Sect. Rep. 25. 10 pp.
- Butler, W. L., and R. J. Downs.
1960. LIGHT AND PLANT DEVELOPMENT. Sci. Amer. 203(6): 56-63.
- Caldwell, M. M.
1968. SOLAR ULTRAVIOLET RADIATION AS AN ECOLOGICAL FACTOR FOR ALPINE PLANTS. Ecol. Monogr. 38(3): 243-268.
- Cunningham, G. C.
1952. RESEARCH IN TOLERANT HARDWOODS. Birch Dieback Symp. Proc.: 52-56. Ottawa, Ont.
- Dixon, R. M.
1963. THE FOREST RESOURCES OF ONTARIO. Ontario Dep. Lands and Forests, Timber Br., 108 pp. Toronto, Ont.
- Drinkwater, N. H.
1957. THE TOLERANT HARDWOOD FORESTS OF NORTHERN NOVA SCOTIA. Can. Dep. N. Affairs and Natl. Resources, Forestry Br. Tech. Note 57. 25 pp.
- Fayle, D. C. F.
1961. HARE BROWSING MAY SPOIL YELLOW BIRCH REGENERATION. Can. Dep. Forestry. Forestry Res. Br. mimeo. 61-14. 10 pp.
- Fayle, D. C. F.
1965. ROOTING HABIT OF SUGAR MAPLE AND YELLOW BIRCH. Can. Dep. Forestry Pub. 1120. 31 pp.
- Hansbrough, J. R.
1952. THE SIGNIFICANCE OF THE FUNGI AND VIRUSES ASSOCIATED WITH BIRCH DIEBACK. Birch Dieback Symp. Proc.: 128-135. Ottawa, Ont.
- Harvey, R. B.
1923. RED AS A PROTECTIVE COLOR IN PLANTS. Ann. Rep. Minn. State Hort. Soc. 279 pp.
- Hatcher, R. J.
1966. YELLOW BIRCH REGENERATION ON SCARIFIED SEEDBEDS UNDER SMALL CANOPY OPENINGS. Forestry Chron. 42: 350-358.
- Hendricks, S. B.
1968. HOW LIGHT INTERACTS WITH LIVING MATTER. Sci. Amer. 219(3): 175-186.
- Hills, G. A.
1959. A READY REFERENCE TO THE DESCRIPTION OF THE LAND OF ONTARIO AND ITS PRODUCTIVITY. Ontario Dep. Lands and Forests Res. Div. 142 pp. Maple, Ont.
- Holowacz, J.
1960. PROGRESS REPORT ON PRESCRIBED BURNING IN THE HARD MAPLE-YELLOW BIRCH COVER TYPE IN ONTARIO. Ontario Dep. Lands and Forests Res. Br. Sect. Rep. (Forestry) 37, 16 pp.
- Horner, R.
1952. MYCOLOGICAL INVESTIGATIONS OF BIRCH IN ONTARIO. Birch Dieback Symp. Proc.: 144-146. Ottawa, Ont.
- Hosie, R. C.
1953. FOREST REGENERATION IN ONTARIO. Univ. Toronto Forestry Bull. 2. 134 pp.
- Jarvis, J. M.
1956. AN ECOLOGICAL APPROACH TO TOLERANT HARDWOOD SILVICULTURE. Can. Dep. N. Affairs and Natl. Resources Forestry Res. Div. Tech. Note 43. 43 pp.
- Jarvis, J. M.
1957. CUTTING AND SEEDBED PREPARATION TO REGENERATE YELLOW BIRCH, HALIBURTON COUNTY, ONTARIO. Can. Dep. N. Affairs and Natl. Resources Forestry Res. Div. Tech. Note 53. 17 pp.
- Kaufman, H., S. M. Vratsanos and B. F. Erlanger.
1968. PHOTO REGULATION OF AN ENZYMIC PROCESS BY MEANS OF LIGHT SENSITIVE LIGAND. Sci. 162(3861): 1487-1488.
- Koroleff, D.
1954. LEAF LITTER AS A KILLER. J. Forestry 52: 178-182.
- Krugman, S.
1956. THE ANTHOCYANIN AND LEUCO-ANTHOCYANINS OF SUGAR PINE SEEDLINGS. Forest Sci. 2(1): 273-280.
- Lemieux, G. J.
1963. SOIL-VEGETATION RELATIONSHIPS IN THE NORTHERN HARDWOODS OF QUEBEC. Proc. Second North Amer. Forest Soils Conf.: 163-176 pp. Corvallis, Ore.
- Leslie, A. P.
1931. REPORT ON THE FOREST REGENERATION SURVEY OF CUTOVER PINE LANDS UNBURNED SINCE LOGGING, ALGONQUIN PARK. 69 pp. Ontario Forestry Br., Toronto.
- Linteau, A.
1948. FACTORS AFFECTING GERMINATION AND EARLY SURVIVAL OF YELLOW BIRCH (*Betula lutea* MICHX.) IN QUEBEC. Forestry Chron. 24: 27-86.
- Logan, K. T.
1965. GROWTH OF TREE SEEDLINGS AS AFFECTED BY LIGHT INTENSITY: I WHITE BIRCH, YELLOW BIRCH, SUGAR MAPLE, SILVER MAPLE. Can. Dep. Forestry Pub. 1121. 16 pp.

- Morawski, Z. J. R., K. B. Turner, and J. T. Basham.
1958. A SURVEY OF THE PATHOLOGICAL CONDITION OF THE FORESTS OF ONTARIO - CULL STUDIES. Ontario Dep. Lands and Forests Timber Div. Rep. 25. 95 pp.
- Raymond, F. L.
1960. AN UNUSUAL WILTING AND DIEBACK OF YELLOW BIRCH SAPLINGS. Can. Dep. Agr. Bi-monthly Prog. Rep. 16(6): 2.
- Redmond, D. R.
1952. TWIG INHABITING FUNGI OF YELLOW BIRCH; TWIG INOCULATIONS OF LIVING BIRCH WITH FUNGI. Birch Dieback Symp. Proc.: 136-137. Ottawa, Ont.
- Redmond, D. R.
1954. VARIATIONS IN DEVELOPMENT OF YELLOW BIRCH ROOTS IN TWO SOIL TYPES. Forestry Chron. 30: 401-406.
- Redmond, D. R.
1957. OBSERVATIONS ON ROOTLET DEVELOPMENT IN YELLOW BIRCH. Forestry Chron. 33: 208-212.
- Redmond, D. R., and R. C. Robinson.
1954. VIABILITY AND GERMINATION IN YELLOW BIRCH. Forestry Chron. 30: 79-87.
- Rowe, J. S.
1959. FOREST REGIONS OF CANADA. Can. Dep. N. Affairs and Natl. Resources Forestry Br. Bul. 123. 71 pp.
- Sinclair, G. A.
1962. PROGRESS REPORT OF PRESCRIBED BURNING IN HARDWOOD STANDS IN ONTARIO. Ontario Dep. Lands and Forests Res. Br. Sect. Rep. 45. 18 pp.
- Sloane, N. H.
1960. AN APPRECIATION OF PRESCRIBED BURNING AS A SILVICULTURAL TOOL IN ONTARIO. Ontario Dep. Lands and Forests, Res. Inform. Paper 1. 12 pp.
- Sykes, J. M.
1964. REPORT ON THE INTERIM RESULTS OF PRESCRIBED SPRING BURNING IN A POOR QUALITY HARDWOOD STAND. Ontario Dep. Lands and Forests Res. Br. Sect. Rep. 49. 13 pp.
- Wang, B. S. P.
1965. SEEDBED CANOPY AND MOISTURE EFFECTS ON GROWTH OF YELLOW BIRCH SEEDLINGS. Forestry Chron. 41: 106-107.
- Wang, B. S. P.
1968. THE DEVELOPMENT OF YELLOW BIRCH REGENERATION ON SCARIFIED SITES. Can. Dep. Forestry. Forestry Br. Pub. 1210. 14 pp.
- Weaver, J. E., and F. E. Clements.
1938. PLANT ECOLOGY. 601 pp. McGraw Hill Book Co., Inc., N.Y.
- Winget, C. H.
1968. SPECIES COMPOSITION AND DEVELOPMENT OF SECOND-GROWTH HARDWOOD STANDS IN QUÉBEC. Forestry Chron. 44: 31-35.
- Zimmerman, P. W., and A. E. Hitchcock.
1939. ACTIVATION OF CINNAMIC ACID BY ULTRAVIOLET LIGHT AND THE PHYSIOLOGICAL ACTIVITY OF ITS EMANATIONS. Contr. Boyce Thompson Inst. 10: 107-200.