Betula *alleghaniensis* **Britton** Yellow Birch

Betu laceae Birch family

G. G. Erdmann

Yellow birch *(Betula alleghaniensis)* is the most valuable of the native birches. It is easily recognized by the yellowish-bronze exfoliating bark for which it is named. The inner bark is aromatic and has a flavor of winter-green. Other names are gray birch, silver birch, and swamp birch. This slow-growing long-lived tree is found with other hardwoods and conifers on moist well-drained soils of the uplands and mountain ravines. It is an important source of hardwood lumber and a good browse plant for deer and moose. Other wildlife feed on the buds and seeds.

Habitat

Native Range

Yellow birch (fig. 1) ranges from Newfoundland, Nova Scotia, New Brunswick, and Anticosti Island west through southern Ontario to extreme southeastern Manitoba; south to Minnesota and northeastern Iowa; east to northern Illinois, Ohio, Pennsylvania to northern New Jersey and New England; and south in the Appalachian Mountains to eastern Tennessee and northeastern Georgia. Southward yellow birch grows at higher elevations, appears more sporadically, and finally is restricted to moist gorges above 914 m (3,000 ft).

The largest concentrations of yellow birch timber are found in Quebec, Ontario, Maine, Upper Michigan, New York, and New Brunswick (96). About 50 percent of the growing stock volume of yellow birch in North America is in Quebec.

Climate

Yellow birch grows in cool areas with abundant precipitation. Its northern limit coincides with the 2” C (35” F) average annual temperature isotherm, and its southern and western limits coincide with the 30” C (86” F) maximum temperature isotherm (31). Although the average annual temperature is about 7” C (45” F) throughout its range, temperature extremes range from -40” C to 38” C (-40” F to 100° F) (45). Annual precipitation ranges from about 1270 mm (50 in) in the East to 640 mm (25 in) in central Minnesota at its western limit. More than half of the precipitation may be snow. Snowfall ranges from 152 to 356 cm (60 to 140 in) and averages 229 cm (90 in) in the north. The growing season ranges from 60 to 150 days and averages about 120 days.

Soils and Topography

Yellow birch grows over a large area with diverse geology, topography, and soil and moisture conditions. In Michigan and Wisconsin it is found on glacial tills, outwash sands, lacustrine deposits, shallow loess deposits, and residual soils derived from sandstone, limestone, and igneous and metamorphic rock (95). Soils are also derived from granites, schists, and shales in other parts of its range.

Growth of yellow birch is affected by soil texture, drainage, rooting depth, stone content in the rooting zone, elevation, aspect, and fertility. Yellow birch grows best on well-drained, fertile loams and moderately well-drained sandy loams within the soil orders Spodosols and Inceptisols and on flats and lower slopes (45). It also grows on Alfisols typical of the humid temperature forest region. Rootlet development is profuse in loam but poor in sand. Even though its growth is poor, yellow birch is often abundant where drainage is restricted because competition from other species is less severe.

In the Lake States birch grows best on well- and moderately well-drained soils and on lacustrine soils capped with loess. Its growth is poor on poorly-drained lacustrine soils, shallow soils over limestone, and coarse-textured sandy loams without profile development (95). Site quality between the best and poorest sites differs by more than 9 m (30 ft) at 50 years.

In the Green Mountains of Vermont birch grows on unstratified glacial till up to 792 m (2,600 ft) *(109)*. Here, thickness of the upper soil horizon as influenced by elevation and aspect have been used to estimate site index-birch grows better at lower elevations than higher elevations and on northeast aspects than southwest aspects.

Associated Forest Cover

Yellow birch is present in all stages of forest succession. Second-growth stands contain about the same proportion (12 percent) of birch as virgin stands. Yellow birch is usually found singly or in small pure groups in mixtures with other species.

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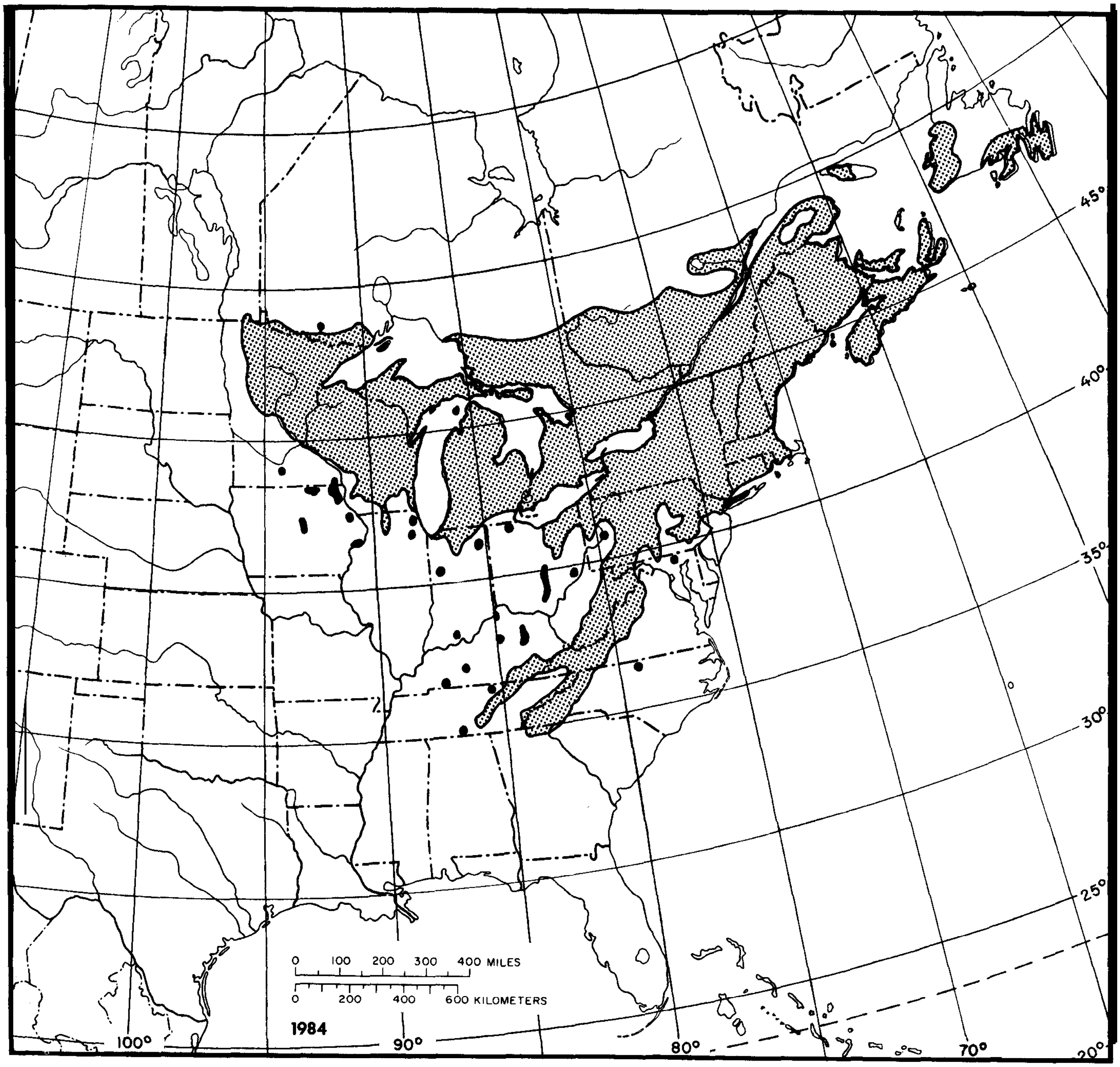

Figure *l-The native* **range** *of yellow birch.*

Because yellow birch is seldom found in pure stands, it is not recognized as a separate type.

Yellow birch is a major component of three forest cover types: Hemlock-Yellow Birch (Society of American Foresters Type 24), Sugar Maple–Beech–Yellow Birch (Type 25), and Red Spruce-Yellow Birch (Type 30) *(41).* Hemlock-Yellow Birch is considered a long-lasting subclimax type, as is Red Spruce-Yellow Birch, except on moist sites, where it is a climax type *(74).*

Yellow birch is a commonly associated species in the following forest cover types *(41):* Balsam Fir (Type 5), Pin Cherry (Type 17), Paper Birch (Type 18), Gray Birch-Red Maple (Type 19), White Pine–Northern Red Oak-Red Maple (Type 20), Eastern White Pine (Type 21), White Pine-Hemlock (Type

22), Eastern Hemlock (Type 23), Sugar Maple–Basswood (Type 26), Sugar Maple (Type 27), Black Cherry (Type 28), Red Spruce-Sugar Maple-Beech (Type 31), Red Spruce (Type 32), Red Spruce-Balsam Fir (Type 33), Red Spruce-Fraser Fir (Type 34), Paper Birch-Red Spruce-Balsam Fir (Type 35), Northern White-Cedar (Type 37), Black Ash–American Elm-Red Maple (Type 39), Yellow-Poplar (Type 57), Yellow-Poplar-Eastern Hemlock (Type 58), Yellow-Poplar-White Oak-Northern Red Oak (Type 59), Beech-Sugar Maple (Type 60), White Spruce (Type 107), and Red Maple (Type 108).

Yellow birch commonly grows in stands with sweet birch *(Betula Zenta)*, eastern hophornbeam *(Ostrya uirginiana)*, *American* hornbeam *(Carpinus caroliniana)*, and as an understory tree in Aspen (Type 16). Small trees and shrubs commonly associated with yellow birch in the north are striped maple *(Acer pensylvanicum)*, mountain maple *(A. spicatum)*, alternate-leaf dogwood *(Cornus alternifolia)*, beaked hazel *(Corylus cornuta)*, Atlantic leatherwood *(Dirca palustris)*, witch-hazel *(Hamamelis virginiana)*, *fly* honey suckle *(Lonicera canadensis)*, American mountain-ash *(Sorbus americana)*, American elder *(Sambucus canadensis)*, Canada *yew (Taxus canadensis)*, mapleleaf viburnum *(Viburnum acerifolium)*, hobblebush *(V. alnifolium)*. Between cliffs of deep, narrow gorges and upper coves of the southern Appalachians, yellow birch is frequently associated with three evergreen shrubs-American holly *(Rex opaca)*, drooping leucothoe *(Leucothoe catesbari)*, and rosebay rhododendron *(Rhododendron maximum)*—and with striped maple, sassafras *(Sassafras albidum)*, and mapleleaf viburnum.

Life History

Reproduction and Early Growth

Flowering and Fruiting-Yellow birch is monoecious; male and female catkins are borne separately on the same branch. Erect staminate catkins are formed during late summer in clusters of two or three, or singly at the tips of long shoots. Individual florets of a staminate catkin contain three flowers and each flower has three bilocular anthers. The greenish staminate catkins, 6 cm (2.2 in) long, remain on the tree over winter. In the spring they turn purplish yellow while elongating to 7 to 10 cm (2.8 to 3.9 in) and then shed pollen for 3 to 5 days. Solitary pistillate catkins also formed during the fall are enclosed in buds over winter; they appear terminally as greenish catkins (each about 2 cm or 0.8 in) on short branchlets with the leaves in late May to early June. Each floret contains three naked flowers and is subtended by a three-lobed bract. Each flower consists of a bicarpellary ovary with two styles. Female flowers are receptive from 2 to 5 days before pollen is shed on the same tree (29). Normally only one of the two ovules in each chamber develops into a seed; the other three abort. Occasionally both ovules within one ovary are fertilized and two seedlings emerge from one seed *(17)*.

The fruit, a winged nutlet, ripens in late August or early September. Each nutlet averages from 3.2 to 3.5 mm (0.13 to 0.14 in) long without the wings. Mature seeds have light brown or tan seed coats and firm white interiors.

Seed Production and Dissemination-Normally, 40 years is considered the minimum and 70 years the optimum seed-bearing age for yellow birch *(45)*, but heavy seed crops are also produced by 30- to 48year-old trees in either open-grown positions or thinned stands. However, open-grown progeny test saplings with large crowns bear viable seed at 7 years and male catkins at 8 years *(21)*. Germinable seed has also been obtained from 16-year-old trees 5 to 10 cm (2 to 4 in) in d.b.h. and 6.7 to 7.6 m (22 to 25 ft) tall.

Good seed crops usually occur at about 2 to 3 year intervals but the frequency of good or better seed crops varies-every 1 to 4 years in northeastern Wisconsin *(47)*, and every 2 to 3 years in Maine, and every 3 years in Ontario *(10)*. Consecutive good or better seed crops only occurred once in the 26-year Wisconsin study; 60 percent of the intervening crops failed or were poor. Seed-crop failures are often caused by hard frost in late spring or early fall or by insects and disease. The percentage of viable seeds produced varies each year and can be very low due to a high proportion of seedcoats without embryos, probably caused by parthenocarpy *(14)*. Seed viability is often affected by weather conditions during pollination, fertilization, and seed development. It also varies by locality, stand, and individual trees within the same stand.

Although some seeds fall shortly after they mature in August, the first heavy seedfall in Canada and the northern United States comes with cold weather in October. Contrary to earlier reports, larger seeds are not shed first nor is their germination capacity any better than that of smaller filled seeds *(17)*.

Yellow birch seeds are light, averaging 99,200/kg (45,000/lb) (8). They are dispersed by the wind and blown up to 400 m (1,320 ft) over crusted snow *(10)*. Dispersal of adequate amounts for regeneration is at least 100 m (330 ft) from the edge of a fully stocked mature northern hardwood stand.

Yellow birch is a prolific seeder, producing between 2.5 and 12.4 million seeds per hectare (1 to 5 million/acre) in good seed years *(45)*, and up to 89 million/ha (36 million/acre) in a bumper seed year *(52)*. Seed viability is usually good in years with heavy seed crops and poor in years with light crops. Germinative capacity in good seed years is still low, however, averaging about 20 percent under natural conditions.

The next seed crop can be estimated from the abundance of the over-wintering male catkins *(88)*. Fairly reliable estimates of the fall yellow birch seed crop can also be obtained from the size of the spring-maturing red maple crop *(47)*.

Yellow birch seedcoats contain a water-soluble germination inhibitor that is inactivated by light *(17)*. Seed dormancy can be broken down artificially either by stratifying the seed in moist peat or sand at 5" C (41° F) for 4 to 8 weeks or by germinating unchilled seeds in a water medium under "cool-white" fluorescent light for more than 20 days. Germination test results are always higher when unchilled rather than stratified seeds are used (8). Following stratification, seeds are germinated at alternating day and night temperatures of 32" C and 15" C (90° F and 59" F) for 30 to 40 days, and alternating temperature of 30" C and 20" C (86" F and 68" F) with at least 8-hour light periods are used for unchilled seeds. Germination percentages exceeding 90 percent are common in good seed years.

Seeds can be stored in tightly closed bottles at from 2 to 4" C (36 to 40" F) for 4 years without losing viability *(17)*. Some seed lots stored well for 8 years and one lot still had 65 percent germination after 12 years *(19)*.

Seedling Development-Yellow birch seeds dispersed in the fall and winter germinate at warm temperatures in early June. Germination is epigeal. In undisturbed stands, yellow birch can only regenerate on mossy logs, decayed wood, rotten stumps, cracks in boulders, and windthrown hummocks because hardwood leaf litter is detrimental to its survival elsewhere *(45)*. In June most seeds germinate in compacted leaf litter that birch radicals and hypocotyls cannot pierce *(10)*. Drying of the litter during the growing season kills most germinants. The remaining seedlings later succumb to frost damage or are smothered by the next leaf fall.

Unless stands have been burned or heavily disturbed by blowdowns or logging, abundant birch regeneration is normally restricted to edges of skidroads or landing areas on well-drained sites. On less-well-drained soils, sufficient moisture remains in the leaf litter to result in adequate establishment if advance regeneration of other species is removed *(117)*.

The most important factors affecting the catch of yellow birch seedlings are an adequate seed supply, favorable weather, proper seedbed conditions, adequate light, and control of competition.

Removing advance regeneration is at least as important as preparing proper seedbeds *(121)*. Scarification fulfills both requirements and, when coupled with opening of the canopy, can greatly increase the initial catch of birch seedlings (45). Optimum seedling survival and growth, however, occur on disturbed humus or mixed humus mineral soil seedbeds in the absence of advance regeneration *(126)*.

Mechanical scarification and prescribed burning are used to prepare receptive seedbeds and eliminate advance regeneration. Scarification should be shallow to mix humus and mineral soil and to expose 50 to 75 percent of the area (46,881. Spring burning during and shortly after leafout in years with abundant male birch catkins may also control competition from advanced regeneration and provide seed for successful birch regeneration. Treatments should coincide with good seed crops because the effects of scarification are largely lost after two or three growing seasons.

Under dense forest canopies (13 and 15 percent of full sunlight) yellow birch roots grow slower than sugar maple seedlings *(81)*. As a result, few yellow birch become established under selection cutting *(43)*.

The optimum light level for top growth and root development of birch seedlings up to 5 years old is 45 to 50 percent of full sunlight (43). The best root-to-shoot ratios are also produced at similar light levels *(86)*. In field studies, the greatest 2-year height growth occurred at the lowest canopy density of 0 to 14 percent, and on mixed humus and mineral soil seedbeds it occurred under canopy densities between 29 and 50 percent *(123)*. Moderate side shade is beneficial to birch seedlings during their first 5 years *(124)*.

Clearcutting small patches or strips provides suitable conditions for yellow birch seedling establishment in the Northeast where rainfall is abundant. Scarified clearcut patches of 0.04 to 0.24 ha (0.1 to 0.6 acre) produce good catches of birch regeneration. Patches are difficult to manage but can be used in uneven-aged management to increase the proportion of birch (43) when groups of mature or defective trees are harvested (85).

In the dry western part of the species range, success with strip clearcutting to regenerate birch has been too variable to generally recommend its use. In

Upper Michigan success depends on a good seed crop, favorable weather, and control of advance regeneration (89). Although strips 20 and 40 m (66 and 132 ft) wide were equally well stocked with birch seedlings after 6 or 7 years in Michigan, strips 20 m (66 ft) wide are about optimum in Canada *(10)*, and strips 15 m (50 ft) wide are recommended in the Northeast (43).

Clearcuttings of 2 to 4 ha (5 to 10 acres) and uniform selection cuttings are not as effective as smaller patches or the shelterwood method for establishing yellow birch stands *(87,90)*. In the western part of its range, birch regenerates best under shelterwood cuttings (48,121). Ten well-distributed yellow birch seed trees per hectare (4/acre) provide an adequate seed supply (88). Otherwise, 0.56 kg/ha (0.5 lb/acre) of stratified (6 to 8 weeks at 5" C (41" C) birch seed can be applied about a week after site preparation in May (46) or unstratified seed can be sown before January (48).

Yellow birch can also be successfully established by planting 2-O stock 15 to 50 cm (6 to 20 in) tall on 0.08 ha (0.2 acre) clearcut patches (97).

Yellow birch seedling growth in the Northeast is limited by inadequate soil fertility in acid sandy subsoils and can be greatly improved by deep fertilizing with phosphorus and lime to correct phosphorus deficiency and aluminum toxicity (61). Aluminum is toxic to roots, especially in subsoils, deficient in magnesium and sulfur. Seedling roots are tolerant of aluminum concentrations or up to 80 p/m but concentration of 120 p/m or more are toxic (84).

Manganese toxicity in seedlings occurs above foliar concentrations of more than 1,300 p/m; concentrations of less than 60 p/m are deficient; and 440 p/m are optimum (64,).

Optimum nursery seedbed density is about 160 seedlings per square meter ($15/ft^2$) (45). Normally 2-O stock averaging 28 cm (11 in) tall with roots 23 cm (9 in) long and 5 mm (0.2 in) in stem caliper is large enough for dormant spring planting. For early starts in the greenhouse, seedlings require at least 2 months of cold storage to break dormancy (34). Containerized planting is feasible *(11,50,115)*. In 3 months seedlings 40 to 50 cm (16 to 20 in) tall can be produced in the greenhouse using 20-hour days with supplemental cool-white fluorescent and incandescent light *(17)*. Growth can also be accelerated by using plastic greenhouses (94).

After 5 years, yellow birch seedlings are normally overtopped by faster-growing species and require complete release from overstory shading for best survival, growth, and quality development. Photosynthetic rates of overtopped seedlings are only 54 to 70 percent of those grown in full sunlight and their dry weights are 66 percent lower *(82)*.

Birch crop trees in Vermont and Michigan seedling stands (up to 2.5 cm or 1 in d.b.h.) have benefited from cleaning or early release *(40,55)*. After 9 years, trees cleaned to within a 2.4 m (8 ft) radius of the bole radius in Michigan exhibited the best stem, crown, and branch characteristics. They averaged 2 cm (0.8 in) larger in d.b.h. and 0.5 m (1.6 ft) taller than the control trees. Shoot growth of yellow birch partly depends upon current photosynthate (73). The shoot elongation period for released saplings (1.5-m or 5-R radius) can be extended up to 30 days by making more light and moisture available to them *(55)*.

Vegetative Reproduction-Yellow birch seedlings and small saplings reproduce from sprouts when cut, but sprouting from larger stems is very poor *(93,111)*.

Greenwood cuttings of birch have been successfully rooted (45) and overwintered (56). The species can also be propagated by grafting *(17)*.

Sapling and Pole Stages to Maturity

Growth and Yield-Yellow birch (fig. 2) requires overhead light, crown expansion space, soil moisture, and nutrients to compete with its faster growing associates. Crop tree release studies in saplings *(39,54,55,57)*, poles *(36)*, and small saw logs (37) in the Lake States and the Northeast demonstrate that 16- to 65-year-old trees respond well to release and can maintain themselves in favorable growing positions throughout their lives. Growth rates, however, gradually decline as trees age.

In the sapling stage, growth rates can be increased up to 8 cm (3 in) per decade by release of dominant and codominant crop tree crowns from all trees whose crowns are within 1.8 to 2.4 m (6 to 8 ft) of the crop trees' crown perimeters (39).

Diameter growth rates of pole-size trees can be increased from 75 to 78 percent by providing the same open growing space between tree crowns as for saplings *(36)*. Dominant and codominant crop trees with well-developed crowns respond best to release. Complete crown release provides adequate crown and root expansion space for optimizing growth rate and quality development in yellow birch. In practice no more than 247 well-spaced crop trees (6.4 m or 21 ft apart) per hectare (100/acre) are released to produce 150 final harvest trees 46 cm or 18 in d.b.h. per hectare (61/acre).

Diameter growth rates of saw log-size trees can also be increased by about 45 percent by either removing two important crown competitors or providing 1.5 m (5 ft) of crown expansion space (37). Through careful tending with even-aged management techniques, trees 46 cm (18 in) in d.b.h. can be produced in less than 90 years.

Even-aged and uneven-aged stocking guides for northern hardwoods have been developed for mixed stands in the Lake States (40,119) and the Northeast (79,113). For even-aged stands these guides suggest leaving a residual stand of 60 to 80 percent of full stocking and retaining increasing amounts of basal areas as stands mature. Only small yields of birch proportional to the amounts of birch saw log volumes are obtained from selectively cut stands. Growth rates and yields from mixed softwood stands are higher (45). The most promising trees for future grade improvement should be left after thinning or crown release. Yellow birch trees are financially mature at 56 cm (22 in) in d.b.h. but the maximum d.b.h. may be 46 cm (18 in) where surface defects prevent improvement to top-grade saw or veneer logs (78).

Yellow birch prunes itself well as long as its crown is allowed to close within 5 or 6 years after release. It can, however, be pruned to 50 percent of its height without reducing growth. Pruning should be done on small, fast-growing trees with small knotty cores to limit discoloration and keep decay organisms from entering wounds (114). Branches up to 5 cm (2 in) in diameter can be pruned flush without causing lumber defects. Most wounds up to 5 cm (2 in) close within 7 years (112).

Yellow birch trees are sensitive to excessive exposure following heavy cutting and commonly develop epicormic branches from dormant buds. Intermediate and suppressed trees feather out more than dominant and codominant trees. Epicormic sprouting increases with intensity of release but is not a serious problem in managed stands where periodic thinnings follow crown closure (36). Sprouting is usually more profuse just beneath the live crown than further down the stem.

In 60- and 80-year-old New Hampshire stands, addition of nitrogen, phosphorus, calcium, and magnesium to the acid subsoil of Spodosols and large dolomitic limestone applications were suggested for alleviating these deficiencies in yellow birch and for correcting aluminum toxicity in the roots and high manganese levels in the leaves (62,631. Zinc application is a more economical way to correct calcium deficiency of stems and leaves and aluminum toxicity of roots (65).

Six percent and 51 percent increases in average S-year basal area growth of 90-year-old trees have been reported from applications of lime and lime plus nitrogen, phosphorus, and potassium, respectively (98). Lime increased crown-sectional area growth of 70-year-old thinned trees in New York 1 year after broadcast application, by making more calcium and magnesium available for uptake (77).

Figure *Z-A* mature *yellow birch tree, 46 cm (18 in) in d.b.h. in Wisconsin.*

Lake States fertilizer studies in a 65-year-old sawtimber stand and two pole-size stands showed no significant diameter growth responses to varying amounts and combinations of nitrogen, phosphorus, and potassium broadcast fertilizer applications that occurred within 3 years of treatment *(37,116).*

Yellow birch is one of the slowest growing components of both old growth and unmanaged second growth northern hardwood forests. D.b.h. growth rates of less than 2.5 cm (1 in) in 10 years are common in unmanaged stands or stands managed under the uneven-aged system. Fifteen-year mortality exceeded ingrowth for birch in selectively cut 45-year-old stands in Wisconsin (35).

Complete tree and component part biomass equations have been published for yellow birch trees from 0.25 to 66 cm (0.1 to 26 in) in d.b.h. and seedlings 0.3 to 1.2 m (1 to 4 ft) tall in Maine *(128)* and in New Brunswick (69).

Site index curves from stem analysis data have been developed for yellow birch growing in northern hardwood stands in northern Wisconsin and Upper Michigan *(12)* and Vermont (26).

The Vermont curves, when corrected, are also applicable in New Hampshire *(110).* In northern Wisconsin and Upper Michigan yellow birch grows on a narrow range of site indexes *(13).* Yellow birch, sugar maple, and red maple have similar site indexes up to age 50 on well-drained soils. On less well-drained soils, yellow birch site index is higher than that of sugar maple. In the Lake States and New England, average site index is about 16.8 to 19.8 m (55 to 65 ft) for birch at age 50. Until age 50 height growth is faster in the Northeast than in the Lake States; after age 50 these height growth patterns are reversed.

In New England mature trees on medium sites have attained a height of up to 30.5 m (100 ft) and a d.b.h. of more than 76 cm (30 in) at age 200 (45). Maturity is normally reached in 120 to 150 years in unmanaged forests (9). The largest specimen on record, near Gould City, MI, is 144 cm (56.7 in) in d.b.h. and 34.7 m (114 ft) tall, with a 30.8 m (101 ft) crown spread. Its cochampion, near Big Bay, MI, is 151 cm (59.5 in) in d.b.h. and 32.6 m (107 ft) tall with a 26.2 m (86 ft) crown spread (58). Yellow birch trees are commonly more than 300 years old and occasionally reach ages of more than 366 years.

Rooting Habit-Yellow birch has an adaptable well-developed, extensive lateral root system. Its roots are capable of either spreading horizontally through shallow soils or penetrating to depths of more than 1.5 m (5 ft) under favorable conditions. Roots often follow old root channels in compacted soil layers. Rooting patterns of older trees in unmanaged stands may be modified by their origin on decayed wood and stumps (fig. 3). Within- and between-tree root grafting is common in birch (42).

Figure *S-Stilt-rooted yellow birch, 23 cm (9 in) in d.b.h., that developed on a rotten stump in an unmanaged stand in Wisconsin.*

Irregularly distributed lateral roots of sapling and pole-size trees often extend well beyond their crown perimeters *(120).* Most root systems have irregular circular or oval shapes. Roots of trees on slopes are usually concentrated along the contour and the uphill side of the stem. Main laterals are close to the soil surface and usually have one or two sinker roots within 1.8 m (6 ft) of the stem. These sinkers often penetrate to impervious layers (53). Replacement root growth is active from leafout (May 5) until late October in southern New Hampshire (99).

Reaction to Competition-Yellow birch is generally considered intermediate in shade tolerance and competitive ability *(45)*. It is more shade tolerant than the other native birches, but less tolerant than its major associates, sugar maple *(Acer saccharum)*, beech *(Fagus* ***grandifolia),*** and hemlock *(Tsuga)*. Yellow birch is the major gap-phase component of the forest cover types Sugar Maple- Beech-Yellow Birch and Hemlock-Yellow Birch. It cannot regenerate under a closed canopy; it must have soil disturbance and an opening in the canopy ***(125).*** It tends to be stable on moist sites but gives way with age to more tolerant species on dry sites.

Yellow birch is often a pioneer species following fires but is usually less abundant than aspen *(Populus)*, pin cherry *(Prunus* ***pensylvanica),*** and paper birch ***(Betula papyrifera).*** Birch seedlings cannot compete successfully with advance regeneration, grass, and herbaceous plants. An allelopathic relation between yellow birch and sugar maple seedlings has been noted *(118)*. Advance sugar maple regeneration offers the stiffest competition in the Sugar Maple-Beech-Yellow Birch cover type, while red maple *(Acer rubrum)* sprouts are the most serious problem on wetter sites in the Lake States.

Damaging Agents-Yellow birch is a very sensitive species that is more susceptible to injury than its common associates. It is windfirm on deep, well-drained loam and sandy loam soils but is subject to windthrow on shallow, somewhat poorly drained soils. Thin-barked yellow birch is susceptible to fire injury. Seedlings and saplings are killed outright by even light surface fires. The fine branching habit of yellow birch makes it susceptible to damage from accumulating ice or snow loads. Large trees are frost hardy *(91)* but late spring frost can kill lo-year-old seedlings, especially on litter seedbeds under full and partial shade. Winter sunscald can be a problem on the south and southwest sides of birch boles. Birch foliage and twigs are injured by wind-borne salt spray. Seed germination is also greatly reduced by 0.20-percent salt concentrations in the soil (6). Simulated acid rain at pH values from 3 up to 4 stimulated birch germination *(80)* but foliar damage occurs at pH levels of 3 or less and seedling growth reductions at pH 2.3 (127). Yellow birch seedlings are tolerant to atmospheric pollution of ozone at 0.25 p/m (67) and sensitive to 3.5 p/m of sulfur dioxide (66).

Post-logging decadence is a localized decline from which most trees recover. It consists of top dying and some mortality following heavy cutting in mature and overmature stands. Yellow birch is more susceptible to root, stem, or crown injury and more severely affected than its common hardwood associates. Weakened trees are often attacked and eventually killed by the bronze birch borer.

A decline of yellow birch and paper birch trees, called birch dieback, caused widespread mortality between 1932 and 1955 in eastern Canada and northeast United States. It affected yellow birches of all sizes, even in undisturbed virgin stands. The first visible symptoms of dieback are similar to those of decadence. Foliage in the upper crown appears small, curled, cupped, yellowish, and thin. Following this, tips of branches die, then dying progresses downward, involving entire branches and often more than half the crown within 2 or 3 years. Trees are usually killed within 3 to 5 years by the bronze birch borer, which with root rot fungi, the gold ring spot virus, and other pests have been considered secondary agents associated with birch dieback. Many researchers have attributed birch dieback to adverse climatic conditions, drought, and increased soil temperature, over an extended period, which caused rootlet mortality that weakened the trees and predisposed them to attacks by the borer. Others have considered overmaturity, past cutting practices, killing of associated trees by disease and the spruce budworm, and defoliating insect outbreaks on birch as initially responsible for weakening the trees. More recently the apple mosaic virus (49) and the “frozen soil” theory (59) have been suggested as the possible triggering mechanisms for birch dieback. Under the “frozen soil” theory, shallow-rooted birch trees in years without snow cover are apparently unable to replace moisture losses from their stems through both frozen rootlets and those broken from frost heaving. To date, no single “triggering” cause of birch dieback has been widely accepted, but the condition is probably the result of one or more of the indicated stress factors.

Top-dying and reduced growth of yellow birch crowns have also been associated with heavy birch seed crops ***(51).*** This dieback occurs the year after bumper seed crops and is limited to the peripheral 0.6 to 0.9 m (2 to 3 ft) of branch tips on mature trees and usually just the past season’s growth on younger trees.

Discoloration and decay are the major causes of defect and loss in wood quality of yellow birch *(75,92)*. Discoloration and decay develop more rapidly in yellow birch than other diffuse-porous northern hardwood species ***(60,107).*** Some of the non-hymenomycetes most frequently isolated from discolored wood associated with birch wounds are *Libertella* ***betulina,*** *Trichocladium* ***canadense, Phialophora*** spp., ***Phialocephala*** spp., ***Hypoxylon*** spp., and ***Nectria*** spp. *(32,103,104,107)*.

Mechnical wounds with more than 320 cm^2 (50 in^2) of exposed wood are important entrance courts for decay fungi ***(92). Pholiota limonella, I? aurivella,***

Polyporus versicolor, Daldinia concentrica, and ***Hypoxylon*** spp. are aggressive invaders of these larger wounds *(76,104,106)*. ***D. concentrica*** and ***Hypoxylon*** spp. also invade branch stubs. Extensive decay is usually associated with larger mechanical injuries more than 20 years old and frost cracks more than 10 years old. Species of ***Phialophora*** are often found in tissues near frost cracks (33). Bacteria, ***Graphium*** spp., ***Phialophora*** spp., ***Polyporus*** spp., ***Pholiota*** spp., and ***Nectria*** are the microorganisms most frequently associated with increment-bore wounds in birch (60). Increment-bore wounds cause reddish-brown decay columns from 74 to 213 cm (29 to 84 in) long within 2 years following boring.

Nectria galligena is the most common and damaging stem disease of yellow birch. It causes perennial targetlike cankers, a twig blight, and subsequent crown dieback (59). The fungus can penetrate saplings, small branches, buds, and wounds but usually enters the host through cracks originating at branch axils from heavy snow or ice loads (7). *Nectria* cankers cause localized defects that reduce stem quality and weaken the stem, increasing the chances for wind breakage (45).

Diaporthe alleghaniensis causes a black sunken canker and shoot blight of yellow birch (1). Natural infections probably enter through bud scale scars, frost cracks, leaf scars, wounds, and other injuries (2). Cankers appear on shoots, stems, and petioles of seedlings in the spring and summer and foliage wilts and browns in the summer. Outbreaks of ***D. alleghaniensis*** occur only when conditions are optimum for infection and growth (70). Normally the fungus is weakly pathogenic and thins out less vigorous and overtopped seedlings.

Gnomonia setacea causes a canker, shoot blight, and leaf spot disease of yellow birch seedlings (71).

Stereum** murrayi* causes elongated, sunken, bark-covered stem cankers and a yellow-brown stringy trunk rot of yellow birch. Cankers are common on branch stubs and decay usually extends about 0.3 m (1 ft) above and below cankers on pole-sized trees (106). Decay can be extensive in overmature yellow birch. ***Phellinus laevigatus also produces characteristic sunken, bark-covered cankers on mature and over-mature trees. Single cankers indicate extensive decay. It is more common on dead than living trees. ***Inonotus obliquus*** produces black, clinker-like, sterile conks that develop in trunk wounds and branch stubs. Sometimes conks of ***I. obliquus*** and *Phellinus* ***igniarius*** occur on dead branch stubs in the center of Nectria cankers. A sterile conk indicates from 50 to 100 percent cull (59) and decay extends from 1.5 to 2.1 m (5 to 7 ft) above and below each conk. *Inonotus* ***obliquus*** is an aggressive decay fungi that can invade and kill tissues around these sterile conks (106).

***Armillaria** mellea,* the shoestring root rot, is the most common and important root and butt decayer of yellow birch trees (106). The fungus causes a white root rot with black rhizomorphs on the roots.

Inonotus obliquus, Pholiota spp., ***Phellinus** igniarius,* and ***I? laevigata*** are the principal decay fungi of yellow birch trunks *(45,76,106)*. The false tinder fungus *(**P. igniarius**)* causes a common white trunk rot of yellow birch. A single conk indicates extensive decay that extends 2.4 to 3.0 m (8 to 10 ft) above and below the conk. ***Pholiota aurivella*** is an aggressive decayer of centers of larger birches and ***Pholiota limonella*** causes a yellow-brown stringy trunk rot.

Ganoderma applanatum usually occurs on dead birches but sometimes rots the centers of trunks and infects roots and butts through wounds ***(106)***. Perennial, hoof-shaped conks of ***Fomes fomentarius,*** the tinder fungus, are common on dead birch. The fungus also has been associated with decay in living and dead branches of dieback birches. ***Piptoporus betulinus, Fomitopsis pinicola,*** and ***Polyporus** lucidus* also are primarily decayers of dead wood but they may extend into centers of living trees (59).

Coniothyrium spp., common twig-inhabiting fungi, injure yellow birch seeds and seedlings ***(108).*** They are associated with weevils that tunnel through the cones and destroy or injure the seeds.

The bronze birch borer *(**Agrilus** anxius)* is the most serious insect pest of yellow birch. It attacks both healthy and weakened birches (83) but apparently can normally complete its life cycle only in dead or dying wood in weakened trees. Mature and overmature trees left severely exposed after logging and in lightly stocked stands are more subject to attack then trees in well-stocked stands. Adults deposit their eggs in bark crevices of upper branches. Grubs hatch, bore meandering tunnels underneath the bark that cause top dying, then move progressively lower down the stem and kill the tree within 2 or 3 years. The Columbian timber beetle ***(Corthylus** columbianus)* bores deep into the sapwood of vigorous birches of all sizes (3). A flatheaded borer ***(Chrysobothris sexsignata)*** occurs commonly on birch in the East. The ambrosia beetle *(Xyloterinus politus)* is a secondary insect that attacks weakened and wounded birches. Adults bore holes through lenticles in the bark and make galleries ***(105).***

In outbreaks, the birch skeletonizer ***(Bucculatrix canadensisella)*** completely destroys foliage by August. Successive attacks reduce host vigor and may predispose birches to bronze birch borer attacks.

Although yellow birch is not a preferred host of the forest tent caterpillar *(Malacosoma disstria),* the gypsy moth *(Lymantria dispar),* the elm spanworm *(Ennomos subsignarius),* the hemlock looper *(Lambdina fiscellaria),* or the saddled prominent *(Heterocampa guttivitta),* caterpillars of these species defoliate birch in severe outbreaks. Two to three years of successive defoliation can kill birch trees (122). Dusky birch sawfly larvae *(Croesus Zatitarsus)* prefer small saplings of gray birch but also defoliate yellow birch saplings by feeding inward along leaf edges *(3).* The lace bug, *Corythucha pallipes,* can be a very injurious insect, especially on young birch (25). A treehopper *(Carynota stupida),* a stink bug *(Elasmuche lateralis),* an aphid *(Euceraphis betulae),* a lygaeid bug *(Kleidocerys resedae germinatus),* and a scale insect *(Xylococculus betulae)* are other commonly to abundantly occurring sucking insects of yellow birch *(3). E. lateralis* and *Kleidocerys resedae germinatus* also feed on catkins. The birch seed midge *(Oligotrophus betheli)* lives in birch seed and makes it infertile.

Yellow birch is a preferred food of the snowshoe hare and the white-tailed deer. White-tails are especially fond of browsing seedlings during the summer, and green leaves and woody stems in the fall, and they favor succulent sprouts over slower growing seedlings. Heavy or repeated browsing often kills seedlings. Moose often severely browse it. Porcupine feeding often damages birch crowns, reduces wood quality, and sometimes kills the trees. Red squirrels cut new germinants, eat seeds, store mature strobiles, and feed on birch sap.

Yellow birch is a favorite summer food source of the yellow-bellied sapsucker on its nesting grounds. Heavy sapsucker feeding can reduce growth, lower wood quality, or even kill birch. The common redpoll and many other songbirds eat yellow birch seed. Ruffed grouse feed on the catkins, seeds, and buds.

Special Uses

Yellow birch lumber and veneer are used in making furniture, paneling, plywood, cabinets, boxes, woodenware, handles, and interior doors. It is one of the principal hardwoods used in the distillation of wood alcohol, acetate of lime, charcoal, tar, and oils (9).

Genetics

Population Differences

Yellow birch shows great phenotypic variability *(17,28).* Significant variation in catkin, fruit, and vegetative characteristics have been reported among birch stands throughout its range *(15,30,102).*

A range-wide study of 55 provenances indicated random variation in seedling height and diameter growth but clinal variation in growth initiation and cessation (17). Similarly, when seedlings grown from seed sources collected along latitudinal and elevational gradients in the Appalachian Mountains were tested, stage of leaf flushing was closely related to latitude but elevation had no influence on stage of flushing and time of growth cessation was more closely related to latitude than elevation (101). Thus, seasonal patterns of shoot elongation and the onset of dormancy in yellow birch appear to be under strong genetic control and probably evolved as an adaption to different photoperiods *(16).* Temperature, however, is also an important factor affecting the breaking of dormancy and cessation of growth *(17,101),* and provenances differ in their chilling requirements. Even though the maximum cold hardiness attained in dormant twigs did not vary by geographic seed source *(44),* overall hardiness apparently does. Seedlings from southern seed sources and low elevations suffered more winter injury in the nursery than those from northern and eastern sources *(24).*

After 5 years, northern seed sources survived better than southern sources in three northern field plantings, but height growth was not related to geographic origin (20). Results of these studies indicate the importance of collecting seed for planting from superior local phenotypes growing on sites similar to the intended planting site.

Within-population variability in morphology, phenology, and growth of yellow birch is large and often exceeds among-population variation. Within-stand variation has been reported in catkin and fruit characteristics *(15),* bark color and exfoliation *(28),* and periodicity of shoot growth *(18,101).* After 5 years in the field, yellow birch families showed within-stand variation in survival, height, diameter, and crown size (23).

Races and Hybrids

Yellow birch trees with fruiting bracts 8 to 13 mm (0.3 to 0.5 in) long have been called var. *macrolepis* (Fern.) Brayshaw. However, because long-bract specimens more than 8 mm (0.3 in) occur throughout the natural range of yellow birch *(15,29,102),* it should not be considered a separate variety. Variety *fallax* (Fassett) Brayshaw is distinguished by its dark brown bark that does not exfoliate in thin shreds as much typical yellow birch bark and resembles bark of nonexfoliating *Betula lenta* L. This dark-barked form occurs in southern Michigan, southern Minnesota, and southern and central Wisconsin, northern Indiana, and northeastern Ohio *(17,27).*

Yellow birch hybridizes naturally with low birch *(Betula pumila* L. var. *glandulifera* Reg.) This hybrid *(B. x purpusii* Schneider) can be separated from its parents by differences in leaf blade length, blade width, stomata1 length, leaf apical angle, number of teeth per side of leaf blade, and pollen diameter (29). Murray birch *(Betula murrayana)* is a new hybrid from southeastern Michigan. It appears to be an octoploid derivative of an unreduced gamete of Purpus birch and a reduced gamete of yellow birch. Murray birch has larger pollen grains and leaf stomata than its supposed ancestors and larger leaves and fruits than Purpus birch *(4).* Mountain paper birch *(B. pupyrifera* var. *cordifolia* (Regel) Fern.) is the natural cross between yellow birch and paper birch *(B. papyrifera* Marsh.). F_1 hybrids are intermediate between their parents in most characteristics but they can be separated by their bark color and texture, samara body width and pubescence, bract lobe length, amount of bractcilia, and the number of leaves per short shoot (5). This hybrid grows better than yellow birch and withstands greater environmental stress *(22).* At *27* years of age, *B. lenta x B. alleghaniensis* hybrids were about 0.9 m (3 ft) shorter in height and 23 mm (0.9 in) smaller in diameter than intraspecific crosses of their parent species (100).

Through controlled pollination the interspecific hybridity of yellow birch and the following species has been verified: *B. papyrifera* Marsh., *B. pumila* L., *B. lenta* L., *B. glandulosa* Michx., *B. pendula* Roth., *B. davurica* Pall., *B. nigra* L., *B. occidentalis* Hook., *B. populifolia* Marsh., *B. mandshurica* (Reg.) Nakai, and *B. pubescens* J. F. Ehrh. *(17,68,72).*

B. alleghaniensis is a hexaploid with normal vegetative cells having 42 pairs of chromosomes. Although some counts as high as 49 have been reported, most provenances have chromosome counts of 42 with a range between 37 and 49 pairs *(17).*

Literature Cited

1. Arnold, Ruth Horner. 1967. A canker and foliage disease of yellow birch. I. Description of the causal fungus, *Diaporthe alleghaniensis* sp. nov., and the symptoms on the host. Canadian Journal of Botany 45(6):783–801.
2. Arnold, Ruth Horner. 1970. A canker and foliage disease of yellow birch. II. Artificial infection studies with *Diaporthe alleghaniensis.* Canadian Journal of Botany 48(9):1525–1540.
3. Baker, Whiteford L. 1972. Eastern forest insects. U.S. Department of Agriculture, Miscellaneous Publication 1175. Washington, DC. 642 p.
4. Barnes, Burton V., and Bruce P. Dancik. 1985. Characteristics and origin of a new birch species, ***Betula murrayana*** from southeastern Michigan. Canadian Journal of Botany 63:223–226.
5. Barnes, Burton V., Bruce P. Dancik, and Terry L. Sharik. 1974. Natural hybridization of yellow birch and paper birch. Forest Science 20(3):215–221.
6. Bicknell, Susan H., and William H. Smith. 1975. Influence of soil salt at levels characteristic of some roadside environments, on the germination of certain tree seeds. Plant Soil 43(3):719–722.
7. Brandt, R. W. 1964. ***Nectria*** canker of hardwoods. USDA Forest Service, Forest Pest Leaflet 84. Washington, DC. 7 p.
8. Brinkman, Kenneth A. 1974. *Betula* L. Birch. *In* Seeds of woody plants in the United States. C. S. Schopmeyer, tech. coord. p. 252-257. U.S. Department of Agriculture, Agriculture Handbook 450. Washington, DC.
9. Brisbin, R. L., and D. L. Sonderman. 1973. Birch an American wood. USDA Forest Service, FS-221. Washington,DC. 11 p.
10. Burton, D. H., H. W. Anderson, and L. F. Riley. 1969. Natural regeneration of yellow birch in Canada. *In* Proceedings, Birch Symposium. p. 55-73. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA.
11. Canavera, Dave. 1978. Effects of various growing media on container-grown yellow birch. Tree Planters' Notes 29(1):12–14.
12. Carmean, Willard H. 1978. Site index curves for northern hardwoods in northern Wisconsin and Upper Michigan. USDA Forest Service, Research Paper NC-160. North Central Forest Experiment Station, St. Paul, MN. 16 p.
13. Carmean, Willard H. 1979. Site index comparisons among northern hardwoods in northern Wisconsin and Upper Michigan. USDA Forest Service, Research Paper NC-169. North Central Forest Experiment Station, St. Paul, MN. 17 p.
14. Clausen, Knud E. 1966. Studies of compatibility in *Betula. In* Joint Proceedings, Second Genetics Workshop of Society of American Foresters and Seventh Lake States Forest Tree Improvement Conference. p. 48-52. USDA Forest Service, Research Paper NC-6 North Central Forest Experiment Station, St. Paul, MN.
15. Clausen, Knud E. 1968. Natural variation in catkin and fruit characteristics of yellow birch. *In* Proceedings, Fifteenth Northeastern Forest Tree Improvement Conference. p. 2-7. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA.
16. Clausen, Knud E. 1968. Variation in height growth and growth cessation of 55 yellow birch seed sources. *In* Proceedings, Eighth Lake States Forest Tree Improvement Conference. p. l-4. USDA Forest Service, Research Paper NC-23. North Central Forest Experiment Station, St. Paul, MN.
17. Clausen, Knud E. 1973. Genetics of yellow birch. USDA Forest Service, Research Paper WO-18. Washington, DC. *28* p.

18. Clausen, Knud E. 1973. Within-provenance variation of yellow birch. *In* Proceedings, Twentieth Northeastern Forest Tree Improvement Conference. p. 90-98. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA.
19. Clausen, Knud E. 1975. Long-term storage of yellow birch and paper birch seed. USDA Forest Service, Research Note NC-183. North Central Forest Experiment Station, St. Paul, MN. 3 p.
20. Clausen, Knud E. 1975. Variation in early growth and survival of yellow birch provenances. *In* Proceedings, Twenty-second Northeastern Forest Tree Improvement Conference. p. 138-148. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA.
21. Clausen, Knud E. 1979. The relation between tree size and flowering in yellow birch saplings. *In* Proceedings, Flowering and Seed Development in Forest Trees: a IUFRO Symposium, Frank Bonner, ed. p. 77-82. USDA Forest Service, Southern Forest Experiment Station, New Orleans, LA.
22. Clausen, Knud E. 1979. The yellow x paper birch hybrid-a potential substitute for yellow birch on problem sites. *In* Proceedings, Thirteenth Lake States Forest Tree Improvement Conference. p. 166-171. USDA Forest Service, General Technical Report NC-50. North Central Forest Experiment Station, St. Paul, MN.
23. Clausen, Knud E. 1981. Survival, growth, and flowering of yellow birch progenies in an open-field test. Silvae Genetica 29:108–114.
24. Clausen, Knud E., and Peter W. Garrett. 1969. Progress in birch genetics and tree improvement. *In* Proceedings, Birch Symposium. p. 86-94. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA.
25. Conklin, James G. 1969. Insect enemies of birch. *In* Proceedings, Birch Symposium. p. 151-154. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA.
26. Curtis, R O., and B. W. Post. 1962. Site-index curves for even-aged northern hardwoods in the Green Mountains of Vermont. Vermont Agricultural Experiment Station, Bulletin 629. Burlington, VT. 11 p.
27. Dancik, Bruce P. 1969. Dark-barked birches of southern Michigan. The Michigan Botanist 8(1):38–41.
28. Dancik, Bruce P., and Burton V. Barnes. 1971. Variability in bark morphology of yellow birch in an even-aged stand. The Michigan Botanist 10:34–38.
29. Dancik, Bruce P., and Burton V. Barnes. 1972. Natural variation and hybridization of yellow birch and bog birch in southeastern Michigan. Silvae Genetica 21:1–9.
30. Dancik, Brace P., and Burton V. Barnes. 1975. Leaf variability in yellow birch *(Betula alleghaniensis)* in relation to environment. Canadian Journal of Forest Research 5(2):149–159.
31. Dansereau, P., and G. Pageau. 1966. Distribution geographique et ecologique du ***Betula alleghaniensis.*** Memoires du Jardin Botanique de Montreal 58. 56 p.
32. Davidson, Jean-Guy E. 1972. Early discoloration and decay processes in yellow birch following artificial inoculations. Dissertation Abstracts International B 33(5):1884.
33. Davidson, Jean-Guy, and Marcel Lortie. 1970. Relevé de microorganisms dans le bois de quelques abres feuillus porteurs de fauts sur le tronc. Le Naturaliste Canadien 97(1):43–50.
34. Donnelly, J. R. 1973. Duration of cold storage alters time required for seedling bud-break. Tree Planters' Notes 24(4):25–26.
35. Erdmann, Gayne G., and Robert R. Oberg. 1973. Fifteen-year results from six cutting methods in second-growth northern hardwoods. USDA Forest Service, Research Paper NC-100. North Central Forest Experiment Station, St. Paul, MN. 12 p.
36. Erdmann, Gayne G., and Ralph M. Peterson, Jr. 1972. Crown release increases diameter growth and bole sprouting of pole-size yellow birch. USDA Forest Service, Research Note NC-130. North Central Forest Experiment Station, St. Paul, MN. 4 p.
37. Erdmann, Gayne G., Richard M. Godman, and Gilbert A. Mattson. 1975. Effects of crown release and fertilizer on small sawlog-size yellow birch. USDA Forest Service, Research Paper NC-119. North Central Forest Experiment Station, St. Paul, MN. 6 p.
38. Erdmann, Gayne G., Richard M. Godman, and Ralph M. Peterson, Jr. 1982. How to release yellow birch in the Lake States. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN. 6 p.
39. Erdmann, Gayne G., Richard M. Godman, and Robert R. Oberg. 1975. Crown release accelerates diameter growth and crown development of yellow birch saplings. USDA Forest Service, Research Paper NC-117. North Central Forest Experiment Station, St. Paul, MN. 9 p.
40. Erdmann, Gayne G., Ralph M. Peterson, Jr., and R. M. Godman. 1981. Cleaning yellow birch seedling stands to increase survival, growth, and crown development. Canadian Journal of Forest Research 11(1):62–68.
41. Eyre, F. H., ed. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC. 148 p.
42. Fayle, D. C. F. 1965. Rooting habit of sugar maple and yellow birch. Canadian Department of Forestry, Publication 1120. Ottawa, ON. 31 p.
43. Filip, Stanley M. 1969. Natural regeneration of birch in New England. *In* Proceedings, Birch Symposium. p. 50–54. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA.
44. George, Milon F., Sunk Gak Hong, and Michael J. Burke. 1977. Cold hardiness and deep supercooling of hardwoods: its occurrence in provenance collections of red oak, yellow birch, black walnut, and black cherry. Ecology 58:674–680.
45. Gilbert, Adrian M. 1965. Yellow birch *(Betula* alleghaniensis Britton). *In* Silvics of forest trees of the United States. H. A. Fowells, comp. p. 104-109. U.S. Department of Agriculture, Agriculture Handbook 271. Washington, DC.
46. Godman, R. M., and G. G. Erdmann. 1981. How to regenerate yellow birch in the Lake States. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN. 4 p.

47. Godman, R. M., and G. A. Mattson. 1976. Seed crops and regeneration problems of 19 species in northeastern Wisconsin. USDA Forest Service, Research Paper NC-123. North Central Forest Experiment Station, St. Paul, MN. 5 p.
48. Godman, Richard M., and Carl H. Tubbs. 1973. Establishing even-age northern hardwood regeneration by the shelterwood method-a preliminary guide. USDA Forest Service, Research Paper NC-99. North Central Forest Experiment Station, St. Paul, MN. 9 p.
49. Gottlieb, A. R., and J. G. Berbee. 1973. Line pattern of birch caused by apple mosaic virus. Phytopathology 63(12):1470–1477.
50. Graber, Raymond. 1978. Summer planting of container-grown northern hardwoods. USDA Forest Service, Research Note NE-263. Northeastern Forest Experiment Station, Upper Darby, PA. 5 p.
51. Gross, H. L. 1972. Crown deterioration and reduced growth associated with excessive seed production by birch. Canadian Journal of Botany 50(12):2431–2437.
52. Gross, H. L., and A. A. Harnden. 1968. Dieback and abnormal growth of yellow birch induced by heavy fruiting. Canadian Department of Forestry, Information Report O-X-79. Forest Research Laboratory, Ontario Region, Sault Ste. Marie, ON. 7 p.
53. Hannah, P. R. 1972. Yellow birch root occupancy related to stump and breast height diameters. Vermont Agricultural Experiment Station, Bulletin 669. University of Vermont, Burlington. 9 p.
54. Hannah, P. R. 1974. Crop tree thinning increases availability of soil water to small yellow birch poles. Soil Science Society of America Proceedings 38(4):672–675.
55. Hannah, P. R. 1974. Thinning yellow birch saplings to increase main leader growth. Vermont Agricultural Experiment Station, Research Paper MP 80. University of Vermont, Burlington. 9 p.
56. Hannah, P. R. 1976. Planting and intensive culture of yellow birch to improve timber quality and production. The Maine Forest Review 10:17–21.
57. Hannah, P. R. 1978. Growth of large yellow birch saplings following crop tree thinning. Journal of Forestry 76(4):222–223.
58. Hartman, Kay. 1982. American Forestry Association. National register of big trees. American Forests 88(4):17–48.
59. Hepting, George H. 1971. Diseases of forest and shade trees of the United States. U.S. Department of Agriculture, Agriculture Handbook 386. Washington, DC. 658 p.
60. Houston, D. R. 1971. Discoloration and decay in red maple and yellow birch: reduction through wound treatment. Forest Science 17(4):402–406.
61. Hoyle, M. C. 1965. Addition of phosphorus to subsoil promotes root development of yellow birch. USDA Forest Service, Research Note NE-42. Northeastern Forest Experiment Station, Upper Darby, PA. 7 p.
62. Hoyle, M. C. 1969. Response of yellow birch in acid subsoil to macronutrient additions. Soil Science 108(5):354–358.
63. Hoyle, M. C. 1969. Variation in content of microelements in yellow birch foliage due to season and soil drainage. Soil Science Society of America Proceedings 33(3):458–459.
64. Hoyle, M. C. 1972. Manganese toxicity in yellow birch *(Betula alleghaniensis)* seedlings. Plant and Soil 37(1):229–232.
65. Hoyle, M. C. 1979. Response of yellow birch *(Betula alleghaniensis* Britton) in acid subsoil to micronutrient additions. Plant and Soil 51(3):453–455.
66. Jensen, K. F., and T. T. Kozlowski. 1975. Absorption and translocation of sulfur dioxide by seedlings of four forest tree species. Journal of Environmental Quality 4(3):379–382.
67. Jensen, Keith F., and Roberta G. Masters. 1975. Growth of six woody species fumigated with ozone. Plant Disease Reporter 59(9):760–762.
68. Johnsson, Helge. 1974. The hybrid *Betula lutea,* sect. *Costatae x Betula occidentalis,* sect. Albae. Silvae Genetica 23(1–3):14–17.
69. Ker, M. F. 1980. Tree biomass equations for seven species in southwestern New Brunswick. Environment Canada, Canadian Forestry Service, Information Report M-X-114. Maritimes Forest Research Centre, Fredericton, NB. 14 p.
70. Kessler, K. J., Jr. 1970. A survey of diseases affecting yellow birch seedlings. Plant Disease Reporter 54(1):16–18.
71. Kessler, K. J., Jr. 1978. Gnomonia canker, shoot blight, and leaf spot of yellow birch. USDA Forest Service, Research Paper NC-152. North Central Forest Experiment Station, St. Paul, MN. 12 p.
72. Konovalov, N. A., and N. P. Pitchugina. 1976. Cytological peculiarities of interspecific birch hybrids. *In* Proceedings, Division 2, Sixteenth IUFRO World Congress, June 20–July 2, 1976, Olso, Norway. p. 298–301. As, Norway.
73. Kozlowski, T. T., and J. Johanna Clausen. 1966. Shoot growth characteristics of heterophyllous woody plants. Canadian Journal of Botany 44(6):827–843.
74. Kujawski, R. F., and Paul C. Lemon. 1969. Ecological effectiveness of yellow birch in several Adirondack forest types. *In* Vegetation-environment relations at Whiteface Mountain in the Adirondacks. p. 162-191. J. Gary Holway and Jon T. Scott, co-investigators. Report 92. State University of New York, Atmospheric Sciences Research Center, Albany.
75. Lavallee, Andre, and Marcel Lortie. 1968. Relationships between external features and trunk rot in living yellow birch *(Betula alleghaniensis, Nectria galligena, Poria obliqua).* The Forestry Chronicle 44(2):5–10.
76. Lavallee, A., and M. Lortie. 1971. Some observations on the germination and viability of basidiospores of *Pholiota aurivella.* Phytoprotection 52(3):112–118.
77. Lea, R., W. C. Tierson, and A. L. Leaf. 1979. Growth responses of northern hardwoods to fertilization. Forest Science 25(4):597–604.
78. Leak, W. B., S. M. Filip, and D. S. Solomon. 1968. Rates of value increase for yellow birch in New England. USDA Forest Service, Research Paper NE-120. Northeastern Forest Experiment Station, Upper Darby, PA. 11 p.
79. Leak, W. B., D. S. Solomon, and S. M. Filip. 1969. A silviculture guide for northern hardwoods in the Northeast. USDA Forest Service, Research Paper NE-143. Northeastern Forest Experiment Station, Upper Darby, PA. 34 p.
80. Lee, Jeffrey J., and David E. Weber. 1979. The effect of simulated acid rain on seedling emergence and growth of 11 woody species. Forest Science 25(3):393–398.

81. Logan, K. T. 1965. Growth of tree seedlings as affected by light intensity: I. White birch, yellow birch, sugar maple, silver maple. Canadian Department of Forestry, Publication 1121. Ottawa, ON. 16 p.
82. Logan, K. T. 1970. Adaptations of the photosynthetic apparatus of sun- and shade-grown yellow birch. *(Betula alleghaniensis).* Canadian Journal of Botany 48(9):1681–1688.
83. MacAloney, H. J. 1968. The bronze birch borer. USDA Forest Service, Forest Pest Leaflet 109. Washington, DC. 4 p.
84. McCormick, L. H., and K. C. Steiner, 1978. Variation in aluminum tolerance among six genera of trees. Forest Science 24(4):565–568.
85. Marquis, David A. 1965. Regeneration of birch and associated hardwoods after patch cutting. USDA Forest Service, Research Paper NE-32. Northeastern Forest Experiment Station, Upper Darby, PA. 13 p.
86. Marquis, David A. 1966. Germination and growth of paper and yellow birch in simulated strip cuttings. USDA Forest Service, Research Paper NE-54. Northeastern Forest Experiment Station, Upper Darby, PA. 19 p.
87. Marquis, David A. 1967. Clearcutting in northern hardwoods: results after 30 years. USDA Forest Service, Research Paper NE-85. Northeastern Forest Experiment Station, Upper Darby, PA. 13 p.
88. Marquis, David A. 1969. Silvical requirements for natural birch regeneration. *In* Proceedings, Birch Symposium. p. 4049. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA.
89. Metzger, Frederick T. 1980. Strip clearcutting to regenerate northern hardwoods. USDA Forest Service, Research Paper NC-186. North Central Forest Experiment Station, St. Paul, MN. 14 p.
90. Metzger, Frederick T., and Carl H. Tubbs. 1971. The influence of cutting method on regeneration of second-growth northern hardwoods. Journal of Forestry 69(9):559–564.
91. Morsink, W. A. G. 1970. A suggested frost injury rating system for clones of trees. Canadian Journal of Botany 48(3):493–497.
92. Ohman, J. H. 1970. Value loss from skidding wounds in sugar maple and yellow birch. Journal of Forestry 68(4):226–230.
93. Perala, Donald A. 1974. Growth and survival of northern hardwood sprouts after burning. USDA Forest Service, Research Note NC-176. North Central Forest Experiment Station, St. Paul, MN. 4 p.
94. Phipps, Howard M. 1969. The germination of several tree species in plastic greenhouses. USDA Forest Service, Research Note NC-83. North Central Forest Experiment Station, St. Paul, MN. 2 p.
95. Post, Boyd W., W. H. Carmean, and Robert 0. Curtis, 1969. Birch soil-site requirements. *In* Proceedings, Birch Symposium. p. 95-101. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA.
96. Quigley, Kenneth L., and Harold M. Babcock. 1969. Birch timber resources of North America. *In* Proceedings, Birch Symposium. p. 6-14. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA.
97. Roberge, M. R. 1977. Influence of cutting methods on natural and artificial regeneration of yellow birch in Quebec northern hardwoods. Canadian Journal of Forest Research 7(1):175–182.
98. Safford, L. 0. 1973. Fertilization increases diameter growth and birch-beech-maple trees in New Hampshire. USDA Forest Service, Research Note NE-182. Northeastern Forest Experiment Station, Upper Darby, PA. 4 p.
99. Safford, L. 0. 1976. Seasonal variation in the growth and nutrient content of yellow birch replacement roots. Plant and Soil 44(2):439–444.
100. Sharik, Terry L., and Burton V. Barnes. 1971. Hybridization in *Betula* alleghaniensis Britt. and *B. lenta* L.: a comparative analysis of controlled crosses. Forest Science 17(4):415–424.
101. Sharik, Terry L., and Burton V. Barnes. 1976. Phenology of shoot growth among diverse populations of yellow birch *(Betula alleghaniensis)* and sweet birch *(Betula lenta).* Canadian Journal of Botany 54(18):2122–2129.
102. Sharik, Terry L., and Burton V. Barnes. 1979. Natural variation in morphology among diverse populations of yellow birch (Betula *alleghaniensis)* and sweet birch *(Betula lenta).* Canadian Journal of Botany 57(18):1932–1939.
103. Shigo, A. L. 1965. Organism interactions in decay and discoloration in beech, birch and maple. USDA Forest Service, Research Paper NE43. Northeastern Forest Experiment Station, Upper Darby, PA. 23 p.
104. Shigo, A. L. 1966. Decay and discoloration following logging wounds on northern hardwoods. USDA Forest Service, Research Paper NE47. Northeastern Forest Experiment Station, Upper Darby, PA. 43 p.
105. Shigo, A. L. 1966. Defects in birth associated with injuries made by *Xyloterinus politus* Say. USDA Forest Service, Research Note NE-49. Northeastern Forest Experiment Station, Upper Darby, PA. 7 p.
106. Shigo, A. L., and Edwin vH. Larson. 1969. A photo guide to the patterns of discoloration and decay in living northern hardwood trees. USDA Forest Service, Research Paper NE-127. Northeastern Forest Experiment Station, Upper Darby, PA. 100 p.
107. Shigo, A. L., and E. M. Sharon. 1968. Discoloration and decay in hardwoods following inoculations with Hymenomycetes. Phytopathology 58:1493–1498.
108. Shigo, Alex L., and George Yelenosky. 1963. Fungus and insect injury to yellow birch seeds and seedlings. USDA Forest Service, Research Paper NE-11. Northeastern Forest Experiment Station, Upper Darby, PA. 11 p.
109. Siccama, Thomas G. 1974. Vegetation, soil, and climate on the Green Mountains of Vermont. Ecological Monograph 44(3):325–349.
110. Solomon, D. S. 1968. Applying site-index curves to northern hardwoods in New Hampshire. USDA Forest Service, Research Note NE-79. Northeastern Forest Experiment Station, Upper Darby, PA. 5 p.
111. Solomon, Dale S., and Barton M. Blum. 1967. Stump sprouting of four northern hardwoods. USDA Forest Service, Research Paper NE-59. Northeastern Forest Experiment Station, Upper Darby, PA. 13 p.
112. Solomon, Dale S., and Barton M. Blum. 1977. Closure rates of yellow birch pruning wounds. Canadian Journal of Forest Research 7(1):120–124.

113. Solomon, Dale S., and William B. Leak. 1969. Stocking, growth, and yield of birch stands. In Proceedings, Birch Symposium. p. 106-118. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA.

114. Solomon, Dale S., and Alex L. Shigo. 1976. Discoloration and decay associated with pruning wounds on yellow birch. Forest Science 22(4):391–392.

115. Stanek, W. 1970. Growing yellow birch seedlings in polyethylene bullet containers. The Forestry Chronicle 46(4):329–331.

116. Stone, D. M. 1977. Fertilizing and thinning northern hardwoods in the Lake States. USDA Forest Service, Research Paper NC-141. North Central Forest Experiment Station, St. Paul, MN. 7 p.

117. Tubbs, C. H. 1969. The influence of light, moisture,, and seedbed on yellow birch regeneration. USDA Forest Service, Research Paper NC-27. North Central Forest Experiment Station, St. Paul, MN. 12 p.

118. Tubbs, C. H. 1973. Allelopathic relationship between yellow birch and sugar maple seedlings. Forest Science 19(2):139–145.

119. Tubbs, C. H. 1977. Manager's handbook for northern hardwoods in North Central States. USDA Forest Service, General Technical Report NC-39. North Central Forest Experiment Station, St. Paul, MN. 29 p.

120. Tubbs, C. H. 1977. Root-crown-relations of young sugar maple and yellow birch. USDA Forest Service, Research Note NC-225. North Central Forest Experiment Station, St. Paul, MN. 4 p.

121. Tubbs, Carl H., and Frederick T. Metzger. 1969. Regeneration of northern hardwoods under shelterwood cutting. The Forestry Chronicle 45(5):333–337.

122. U.S. Department of Agriculture, Forest Service. 1979. A guide to common insects and diseases of forest trees in the northeastern United States. Forest Insect and Disease Management, NA-FR-4. Northeastern Area State and Private Forestry, Broomall, PA. 127 p.

123. Wang, B. S. P. 1965. Seedbed canopy and moisture effects on growth of yellow birch seedlings. The Forestry Chronicle 41(1):106–107.

124. Wang, B. S. P. 1968. The development of yellow birch regeneration on scarified sites. Canadian Department of Forestry and Rural Development, Forest Branch Department Publication 1210. Ottawa, ON. 14 p.

125. Winget, C. H., and T. T. Kozlowski. 1965. Yellow birch germination and seedling growth. Forest Science 11(4):386–392.

126. Winget, C. H., G. Cottam, and T. T. Kozlowski. 1965. Species association and stand structure of yellow birch in Wisconsin. Forest Science 11(3):369–383.

127. Wood, Tim, and F. H. Bormann. 1974. The effects of an artificial acid mist upon the growth of *Betula alleghaniensis* Britt. Environmental Pollution 7(4):259–268.

128. Young, Harold E., John H. Ribe, and Kevin Wainwright. 1980. Weight tables for tree and shrub species in Maine. Maine Life Sciences and Agricultural Experiment Station, Miscellaneous Report 230. University of Maine, Orono. 84 p.