Betula papyrifera Marsh. Paper Birch

Betulaceae Birch family

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Typical paper birch (*Betula papyrifera* var. *papyrifera),* also called white birch, canoe birch, or silver birch, and the other five intergrading geographical varieties, western paper birch (*B. papyrifera* var. *commutata* (Regel) Fern.), mountain paper birch (*B. papyrifera* var. *cordifolia* (Regel) Fern.), Kenai birch (*B. papyrifera* var. *kenaica* (W. H. Evans) Henry), Alaska paper birch (*B. papyrifera* var. *neoalaskana* (Sarg.) Raup), and northwestern paper birch (*B. papyrifera* var. *subcordata* (Rydb.) Sarg.) are the most widely distributed birches in North America, mostly in Canada. These medium-sized, fast-growing trees develop best on well-drained, sandy loams on cool moist sites. They are commonly found in the mixed hardwood-conifer forests but may form nearly pure stands where they pioneer areas disturbed by fires or logging. Paper birch is short-lived and rarely lives more than 140 years. Commercially the lumber is used for veneer, pulpwood, and many specialty items. The handsome foliage and showy white bark make the trees attractive for landscaping. They are important browse plants for animals, and the seeds, buds, and bark are also eaten by wildlife.

Habitat

Native Range

The range of paper birch (figs. 1, 2) closely follows the northern limit of tree growth from Newfoundland and Labrador west across the continent into northwest Alaska; southeast from Kodiak Island in Alaska to British Columbia and Washington; east in the mountains of northeast Oregon, northern Idaho, and western Montana with scattered outliers in the northern Great Plains of Canada, Montana, North Dakota, the Black Hills of South Dakota, Wyoming, Nebraska, and the Front Range of Colorado; east in Minnesota and Iowa, through the Great Lakes region into New England. Paper birch also extends down the Appalachian Mountains from central New York to western North Carolina *(46,58,97,112).*

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Climate

Paper birch is a northern species adapted to cold climates. Its range is bounded on the north by the 13° C (55° F) July isotherm and in the south, it seldom grows naturally where average July temperatures exceed 21” C (70” F). In Alaska, paper birch is found on the cooler north and east aspects and aspen on the warm south and west aspects. The variety *cordifolia* in the east generally grows in the cooler habitats-upper elevations on mountains near tree line in the southern part of the range and on cooler north aspects and in depressions toward the northern part of its range.

Paper birch tolerates wide variations in the patterns and amounts of precipitation. In Alaska, annual precipitation averages only about 300 mm (12 in); more than half of this as rain in summer and fall. At higher elevations in eastern mountains, precipitation averages as high as 1520 mm (60 in). In general, the climate where paper birch is found has short cool summers and long cold winters during which the ground is covered with snow for long periods *(39,46,67,97).*

Soils and Topography

As might be expected from its wide range and genetic diversity, paper birch grows on almost any soil and topographic situation ranging from steep rocky outcrops of the mountains to flat muskegs of the boreal forest (Histosols). Best development and growth are on the deeper well-drained to moderately well-drained Spodosols, Inceptisols, and Entisols common to glacial deposits throughout its range. In Alaska, best development occurs on Inceptisols developed on loess deposits. Paper birch was found in all habitats described for the White Mountains of New Hampshire and occurred in 50 percent or more of the plots in six of these habitats. Poorest site-index values were obtained for the driest and wettest sites of the range sampled, whereas higher values were obtained for the moist and nutrient enriched habitats *(56).*

In New England, paper birch tends to be more abundant on the dry sites than on the wet or poorly drained soils *(46,63).* In Alaska, where paper birch and aspen (*Populus tremuloides)* occur in mixed stands, birch predominates on the cooler, moister sites, and aspen on the warmer, drier sites. Birch

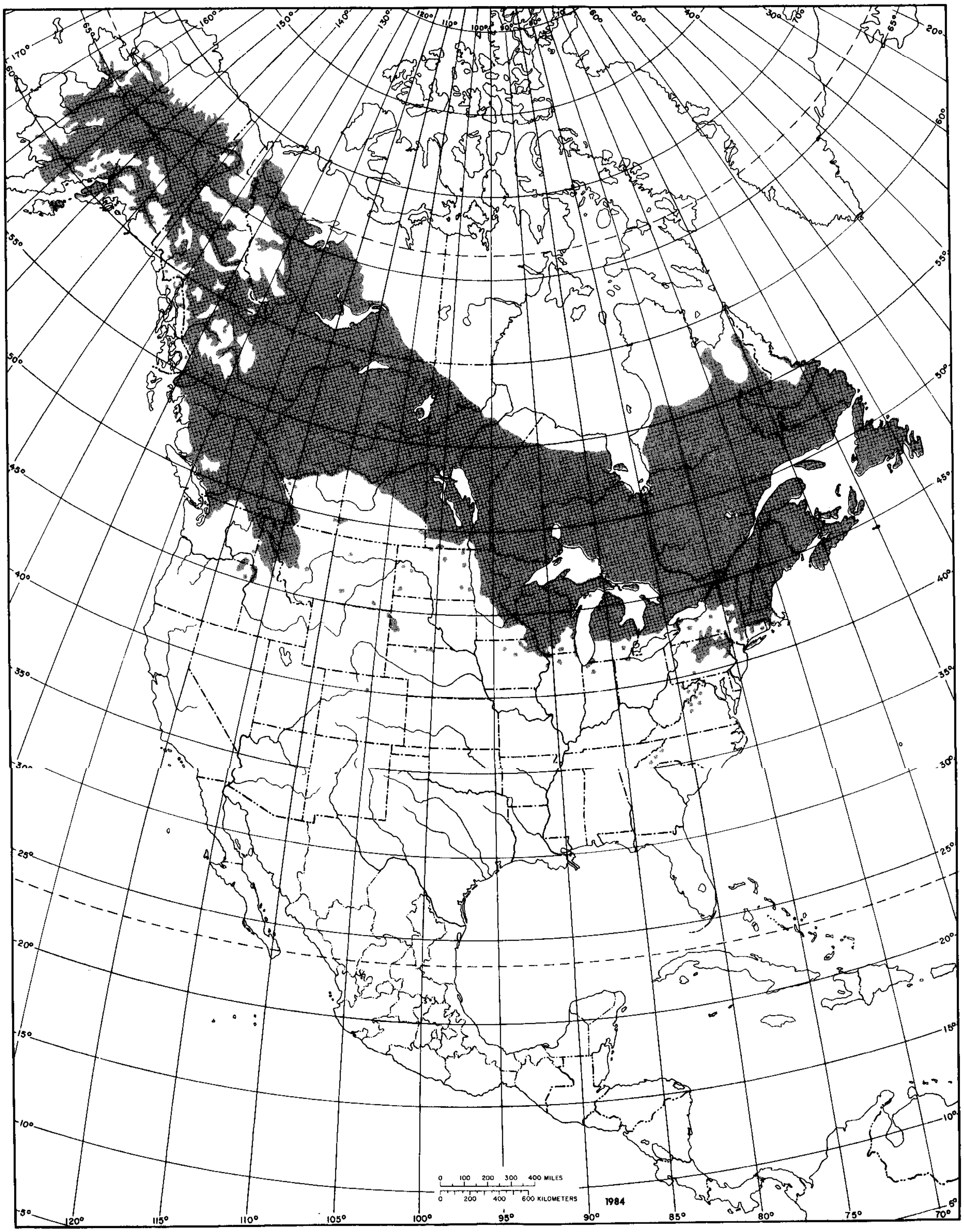
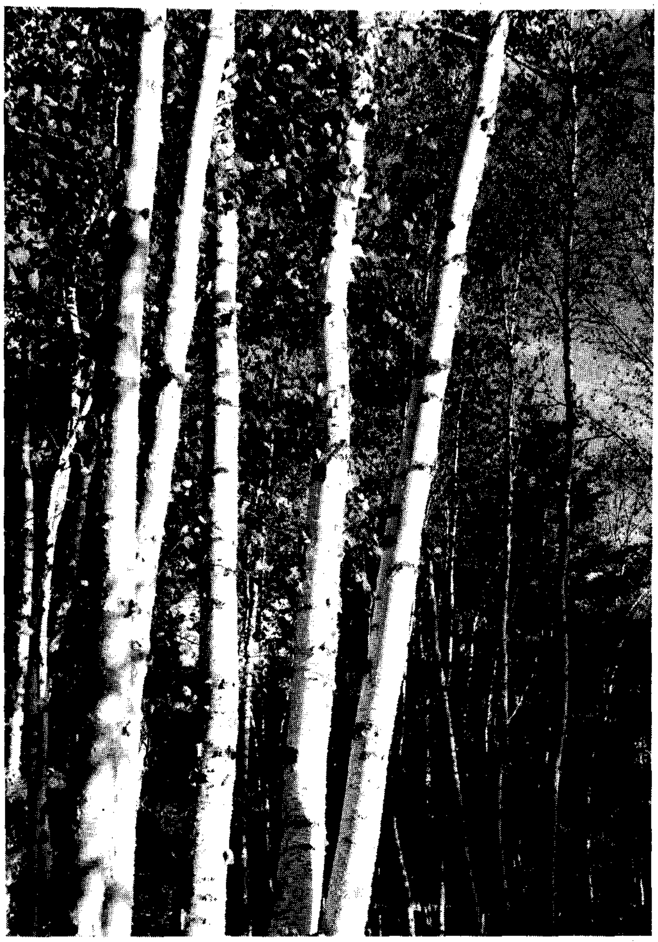


Figure 1-*The native range of paper birch.*



Figure

also can be found with black spruce *(Picea mariana)* on north-facing slopes *(67).*

Typical soil temperatures of birch stands in the Fairbanks region of Alaska range from 9” to 11” C (48” to 52” F) at a 10 cm (4 in) depth during the June to August growing season *(112).* Paper birch grows best in soils free of shallow permafrost. But on north slopes, vigorous sapling birches have been observed where the annual depth of thaw in permafrost was only 64 to 76 cm (25 to 30 in) (67).

Paper birch litter contributes to the nutrient status of the forest floor. When compared with red pine *(Pinus resinosa),* litter under birch was found to be enriched with calcium, potassium, magnesium, phosphorus, and boron and reduced in manganese, aluminum, iron, and zinc. Enrichment extended into the top 3 cm (1.2 in) of the mineral soil where concentrations of calcium, nitrogen, phosphorus, magnesium, potassium, and volatile matter and pH were increased. These increases resulted from the more rapid rate of decomposition of litter under birch than under red pine (93). In Alaska, biomass averaged 60 to 70 t/ha (27 to 31 tons/acre) with an annual litter fall of 4 to 8 t/ha (1.8 to 3.6 tons/acre). In birch stands, rain in the form of throughfall contained from one-half to one-third the calcium and magnesium and twice as much manganese as throughfall under aspen (112). Acidity of precipitation decreased as it passed through crowns of paper birch and other species in New Brunswick, Canada. However, acidity of stemflow increased for paper birch, red pine, white pine, red spruce, and black spruce, where as acidity of stemflow decreased for aspen, red maple, and white spruce *(60).* Total forest floor biomass and content of magnesium, iron, and manganese were greater and calcium was less under birch than aspen *(95).*

Soils under birch and aspen tend to be warmer but drier than soils under the softwoods. Consequently, CO^2 production is limited by lack of moisture under these two hardwoods and by low temperature under the conifers (82).

Paper birch tolerates fairly high levels (up to 80 mg/l) of aluminum in nutrient solution with no reduction of root growth (64). This tolerance varies significantly among provenances with some tolerating much higher levels (up to 120 mg/l) (90). Radicle elongation of paper birch seed germinated on filter paper treated with 1 to 5 mg/l of copper, nickel, or cobalt was reduced about 25 percent. Higher concentrations of these elements (up to 100 mg/l) were required for reduction of radicle elongation on mineral or organic soil. Conifer seeds were less sensitive than paper birch to the same treatments *(71).*

Associated Forest Cover

Paper birch is a common associate of 38 northern forest types. In the east and central regions, it is a major component of two forest cover types (29): Paper Birch (Society of American Foresters Type 18) and Paper Birch-Red Spruce-Balsam Fir (Type 35). In Alaska and western North America, it is an integral member in three types: Paper Birch (Type 252), White Spruce-Paper Birch (Type 202), and Black Spruce-Paper Birch (Type 254).

Paper birch forms either pure stands or mixtures of varying proportions in all regions. Pure stands are generally succeeded by other species *(57),* but some remnant birch can be maintained in openings in stands of other species thought to be climax for a given locality (47). In other instances, intimate mixtures with long-lasting types are characteristic. On the Laurentian highlands of eastern Canada, aspen and birch stands establish within 30 years following fire. Pure stands of conifers-jack pine or black spruce-follow. As the conifers age and openings occur, paper birch re-enters the stands, becoming a younger component of the mature conifer forests. Fire returns at about 130-year intervals *(20).*

Shrubs commonly associated with paper birch in the eastern part of its range are beaked hazel ***(Corylus cornuta),*** common bearberry ***(Arctostaphylos uva-ursi),*** dwarf bush-honeysuckle *(Diervilla* ***lonicera),*** winter-green ***(Gaultheria** procumbens)*, wild sarsaparilla ***(Aralia** nudicaulis)*, blueberries *(Vac-**cinium*** spp.), raspberries and blackberries *(Rubus* spp.), American and redberry elder ***(Sambucus canadensis*** and ***S.*** *callicarpa)*, and hobblebush ***(Viburnum** alnifolium).*

Shrubs common to the Alaskan interior paper birch type are American green alder *(Alnus crispa)*, Scouler willow *(**Salix scouleriana),*** highbush cranberry ***(Viburnum** edule)*, Labrador-tea *(Ledum groenlandicum)*, raspberry *(Rubus* spp.), and roses ***(Rosa*** spp.).

Life History

Reproduction and Early Growth

Flowering and Fruiting-Paper birch flowers from mid-April through early June depending on location. The flowers are monoecious *(8).* In the late summer, staminate flowers are preformed in aments (catkins) 2 to 2.5 cm (0.75 to 1 in) long at the ends of twigs and lateral shoots. These mature and grow in length to 4 to 10 cm (1.5 to 4 in) in the following spring. Pistillate flowers are borne in cylindrical aments (catkins) 2.5 to 5 cm (1 to 2 in) long and 8 mm (0.33 in) in diameter on the same tree. Two or three (rarely four) aments cluster on lateral spur shoots and disintegrate when mature. Fruits are winged nutlets 1.5 mm (0.06 in) long by 0.8 mm (0.03 in) wide with styles 0.8 mm (0.03 in) long. The shape of bracts of the pistillate catkins is characteristic for the species, and variations are useful in distinguishing varieties. The seeds ripen from early August until mid-September. Seed dispersal begins soon after ripening and occurs earlier in injured trees than in healthy trees *(46).* Some seeds fall as early as July as a result of birds feeding on the developing catkins.

Seed Production and Dissemination-Under normal conditions, paper birch begins producing seeds at about 15 years of age, and optimum seed-bearing age is 40 to 70 years. However, seedlings grown in pots for one extended growing season in a greenhouse produced viable seeds (66 percent germination capacity) during the second season of growth under natural conditions out-of-doors *(79).* In mature stands, good seed crops occur every other year on the average, but some seeds are produced in most areas every year. Seed years vary with locality, so information specific to the area of interest is required for planning regeneration treatments. Some information can be gained by observing male catkins the fall before a seed year. An abundance of male catkins may mean a potentially good seed year, because both biotic and abiotic factors can destroy a potentially good crop. Lack of male catkins means a poor seed year. In average seed years, nearly 2.5 million seeds per hectare (1 million/acre) are produced and bumper years have 86 million or more seeds per hectare (35 million/acre). In a mature stand in Alaska, total dry weight of catkins was 6.8 kg (15 lb) per tree, yielding almost 9 million seeds *(106).* Discolored and empty seeds make up 14 to 47 percent of the crop, the lowest proportion of empty and discolored seeds occurs in the best seed years *(4,7,8,63,108).*

Some paper birch seeds may be collected from August through the following spring, but most are dispersed during the months of September through November in both the eastern and western portions of the range (4,107). In Alaska, some seeds were caught in seed traps every month. The rate was less than 10 million/ha (4 million/acre) for December through August whereas it averaged 70 to 90 million/ha (28 to 36 million/acre) for September through November ***(106).*** Time of dispersal does not depend on size of seed crop (7) but varies among stands and from year to year depending upon weather conditions. Seeds that fall in late fall and winter have higher germination capacity than those that fall early (4).

Extremely heavy seed crops can result in crown deterioration and reduced growth. In an Ontario stand, foliage was dwarfed or missing; buds in terminal portions of branches did not develop; and terminal growth and diameter growth were reduced when an extremely heavy seed crop was produced *(41).*

The light, winged paper birch seeds (3 million/kg or 1.4 million/lb) are dispersed readily by the wind, and some seeds travel great distances, particularly when blown across the surface of snow. However, the majority of seeds fall within the stand where they are produced, and seedfall drops off rapidly with distance from the stand edge into clearcut openings. When seedfall within an undisturbed stand was compared with seed fall in a clearcut, seed catch was reduced by 40 percent at the stand edge and 90 percent at the center of the 100-m (330-ft) square opening. On the basis of these observations, it was estimated that a seed crop of 5 million/ha (2 million/acre) would be required to regenerate openings as large as 50 m (165 ft) wide (4). Similar results were obtained in Alaska where 30 to 40 million seeds per hectare (12 to 16 million/acre) were estimated at 40 m (132 ft) from the stand edge, and 0.5 to 0.7 million/ha (0.2 to 0.3 million/acre) were estimated at 100 m (330 ft) *(106)*. Seed crops in interior Alaska are adequate for regeneration of clearcuts as wide as 30 m (100 ft) at least 1 in every 4 years *(108)*.

Under test conditions, paper birch seeds need no pretreatment for germination if tested under light at 20° to 25" C (68" to 77" F) *(8,26,104)*. Seeds germinate in the dark if given either a prechilling or red light treatment; the red light effect can be reversed by far-red light, indicating that germination readiness is phytochrome mediated (2). Germination at low temperatures 5" to 10" C (41° to 50" F) under light is also enhanced by prechilling (26).

In the field, germination generally follows one of two patterns: either germination starts as soon as environmental conditions are suitable and continues until all viable seed have germinated (19); or an initial burst of germination is followed by a period of low germination as seedbeds dry out, and when rainfall replenishes soil moisture, a second peak of germination occurs later in the summer *(110)*.

The proportion of sound, viable seed varies greatly among seed lots of paper birch. This proportion of viable seed can vary among seed years, localities, and specific mother trees (2). Some individuals may produce heavy seed crops frequently with consistently low (10 percent or less) germination *(106)*. The percentage of viable seed can be estimated by examining embryo development with transmitted light under a dissecting microscope (8).

Paper birch seed may be stored for at least 2 years at room temperature if the moisture content is maintained at less than 5 percent *(8)*. Longer storage, up to 8 years, with only slight loss of germination capacity is possible when seeds are stored at 2" to 4° C (35" to 40" F) in sealed containers and at low moisture *(17,79)*. After long storage, viability of each seed lot should be verified by a germination test before the seeds are used, because some seed lots do lose viability *(17)*.

Seedling Development-Germination is epigeal (8). Because of the small size of paper birch seed, newly germinated seedlings are very fragile. They are sensitive to moisture, temperature, light, and seedbed condition (46). Best germination occurs on mineral soil; germination on humus is reduced by about 50 percent, and germination on undisturbed litter is only 10 percent of that obtained on mineral soil. Shaded sites produce about twice as many germinants as full-sun sites. In a partially wind-thrown conifer forest, paper birch seedlings colonized windthrow pit and mound microsites, but most established seedlings were on rotting logs, stumps, and tree boles *(100)*. Early survival of seedlings follows similar patterns, but initial height growth is better on humus than on undisturbed sites, probably because of greater nutrient availability. At the end of the first growing season, birch seedlings growing in full sunlight on mineral soil averaged 5 cm (2.0 in) tall compared with 12 cm (4.7 in) for those on humus. Maximum heights on the same seedbeds were 42 cm (16.5 in) for seedlings on humus and 20 cm (7.9 in) for those on mineral soil. Heights of seedlings in shaded locations on those same seedbeds were about one-half the maximum values *(61,621.* However, paper birch may grow well in about 50 percent of full sunlight. In a study of response to shading, paper birch seedlings grew taller under 45 percent sunlight than when grown in 100, 25, or 13 percent of sunlight. Total dry weight was equal for seedlings grown under 45 percent and 100 percent full sunlight (59).

In Alaska, 3 years following clearcutting, scarified sites were 100 percent stocked, with an average of 1.7 million birch seedlings per hectare (0.7 million/acre). Unscarified seedbeds were only 30 percent stocked with an average of 50,000 seedlings per hectare (20,000/acre) *(109)*. Paper birch seedlings averaged 28 cm (11 in) in height on the scarified plots and 5 cm (2 in) on the unscarified plots after 2 years *(112)*. This difference in results from those in the Northeast is probably caused by severe competition from herbaceous and other vegetation that became established on the unscarified plots. On an upland black spruce site subjected to burning treatments, best germination, survival, and 3-year growth occurred on heavily burned microsites *(111)*.

After 5 years, in a Maine site-preparation study, there were more paper birch seedlings on disked sites than on burned or logged-only sites. But, after 10 years, the total number of birch seedlings, as well as the number of potential crop trees, was greater on the burned treatment than on either the disked or logged-only treatments *(3,5)*:

Treatment	Thousands of seedlings		Potential crop trees	
	5 yr	*10 yr*	*10 yr*	**Height** *10 yr*
			per ha	***m***
Burn	47	12	1191	2.1
Disk	124	8	232	1.5
Log only	25	4	497	2.1
			per acre	***ft***
Burn	19	5	482	7
Disk	50	3	94	5
Log only	10	2	201	7

Following clearcutting or other disturbances, the bulk of paper birch regeneration becomes established during the first growing season from seeds that fell the previous fall and winter. Data for Alaska indicate that 88 percent of seedlings present at age 5 germinated during the first growing season following clearcutting and scarification, 8 percent during year 2, and 4 percent during year 3. About 20 percent of the first-year germinants were still alive after 5 years; 7.4 million/ha (3 million/acre) the first year and 1.7 million/ha (0.7 million/acre) the fifth year (110). Some birch seed may lie dormant in the forest floor for a year or more, especially following heavy seed crops and dry years when conditions for germination are poor *(31,34,38,112).* This dormant seed may be an important source of germinants in poor seed years (74).

Seedlings of the variety ***cordifolia*** are slower growing than typical paper birch. When planted together under similar conditions in Quebec, typical paper birch grew to a height of 3.0 m (9.8 ft) in 5 years against 1.2 m (3.9 ft) for variety ***cordifolia (13,39).***

In the Northeast, clearcutting stands younger than 100 years to regenerate paper birch often results in severe competition from large numbers of seedlings of ***Rubus*** spp. and pin cherry ***(Prunus pensylvanica),*** so that weeding or cleaning is needed to ensure satisfactory birch stocking (61). Large numbers of seeds of these species are stored in the forest floor in stands younger than 100 to 120 years old (36). Longer rotations are recommended to diminish the population of stored seeds and the consequent competition following disturbance.

Even though natural regeneration of paper birch is obtained readily, planting of seedlings may sometimes be desired (45). In planting old fields, site preparation to remove sod is required for satisfactory survival and growth. Protection from girdling by rodents and browsing by deer may be required in some locations (6). Planting stock can be either conventional bare-root stock or container-grown seedlings (35).

Seasonal height growth often begins while minimum temperatures are below freezing, rises gradually to a peak of maximum growth in mid-June, and then drops off gradually. Compared to other species, paper birch has a long period of height growth. Seedling height growth may be prolonged indefinitely under long-day conditions, whereas short days cause terminal growth to stop *(27,46).*

Diameter growth starts after maximum temperatures reach 21° C (70" F) or more and minimum temperatures are above freezing. Temporary abrupt increases and decreases in diameter growth in the spring and fall are correlated with a sudden rise and fall of temperature but not with rainfall. Diameter growth ceases well before either moisture or temperature becomes limiting. In general, paper birch begins and ceases diameter growth later than most of its associates (46).

Vegetative Reproduction-Paper birch can regenerate from sprouts following cutting or fire. Prolific sprouting usually occurs when young, vigorous trees have been cut in the spring to stump heights of 15 to 30 cm (6 to 12 in) (46). Whereas sprouts are seldom abundant enough to reproduce mature stands, they can be valuable supplements to seedlings, particularly on droughty or other difficult sites (63). In an early study of mature stands in Maine, 77 percent of the stumps sprouted, but only 27 percent had live sprouts after 2 years. Heavy browsing by deer was an important factor in sprout mortality (46). In Alaska, 85 to 99 percent of the paper birch stumps sprouted in stands as old as 55 years of age. Sprouting decreased to less than 50 percent in stands greater than 125 years old (106). Ten years after clearcutting and site preparation in a 70-year-old stand in Maine, sprouts were 34 percent of the potential crop trees on logged-only sites. Severe site preparation treatments of disking and burning reduced the number of sprouts as potential crop trees from 299/ha (121/acre) in the winter-logged treatment to 67/ha (27/acre) on burned plots and 32/ha (13/acre) on disked plots (5). Sprouting also may occur at the base of standing live trees that have been subjected to increased exposure by removal of nearby trees (46). Sprouts tend to mature earlier (age 50 to 60 years) and deteriorate sooner (age 70 to 90 years) than trees of seedling origin. Final quality is usually lower for sprouts (63).

Paper birch can be propagated by grafting, air-layering *(18),* rooting of cuttings, or tissue-culture techniques. Cuttings from seedlings root sooner and at higher percentages than cuttings from mature trees. Eighty percent of stem and branch cuttings from 8- to lo-week-old paper birch seedlings rooted within 45 days when placed in 10 percent Hoagland's solution (no. 2) under a 16-hour photoperiod (44). Apical cuttings collected in July from l&year-old paper birch and treated with indolebutyric acid (IBA) rooted better than cuttings collected on earlier or later dates with or without IBA treatment. Some individual trees consistently rooted better (over 40 percent), others consistently poorer (less than 20 percent), regardless of date of collection or hormone treatment of the cuttings (73). Stem segments and axillary buds from new germinants or 1- to 2-year-old seedlings proliferate into callus and multiple plantlets on a medium containing zeatin and adenine sulphate. These plantlets can be successfully

Table l-Yield of fully stocked stands of paper birch in Alaska *(40)*, Ontario *(72)*, and New England (63) by site index

Site index and location	Stand age in years					
	30	40	50	60	70	80
			m^3/ha			
13.7 m						
Alaska	—	—	16	46	76	103
Ontario	11	40	65	84	96	101
New England	51	88	122	148	167	185
16.8 m						
Alaska	—	23	62	107	147	177
Ontario	35	72	105	133	152	165
New England	63	108	150	180	205	226
19.8 m						
Alaska	10	54	118	180	231	267
Ontario	59	104	145	180	209	230
New England	74	128	177	213	242	267
			ft^3/acre			
45 ft						
Alaska	—	—	229	657	1,086	1,471
Ontario	157	571	929	1,200	1,371	1,443
New England	729	1,257	1,743	2,114	2,386	2,643
55 ft						
Alaska	—	329	886	1,529	2,100	2,529
Ontario	500	1,029	7,500	1,900	2,171	2,357
New England	900	1,542	2,143	2,571	2,929	3,229
65 ft						
Alaska	143	771	1,686	2,571	3,300	3,814
Ontario	843	1,486	2,071	2,571	2,986	3,286
New England	1,057	1,829	2,529	3,043	3,457	3,814

transplanted to pots in a greenhouse and subsequently into the field (65). High rooting percentages in mature birch can be restored by establishing young plants through tissue culture techniques for a source of cuttings (92).

Sapling and Pole Stages to Maturity

Growth and Yield-Young paper birch (fig. 3) grows rapidly. Individual trees often have a diameter of 20 cm (8 in) after 30 years. With age, the growth rate declines, and in old age it becomes almost negligible (46). Trees in mature stands average 25 to 30 cm (10 to 12 in) in d.b.h. and 21 m (70 ft) in height. On the best sites, an occasional tree in old stands may exceed 76 cm (30 in) in d.b.h. and 30 m (100 ft) in height. Trees of the variety *cordifolia* are as large as 102 cm (40 in) in d.b.h. (46,991.

Yields at maturity on good sites are similar for Alaska, Ontario, or New England at 230 to 270 m^3/ha (3,286 to 3,857 ft^3/acre) (table 1). On poor sites, yields range from about 100 to 185 m^3/ha (1,429 to 2,643 ft^3/acre). New England stands produce the greatest yields for all age classes and site qualities. Yields in Ontario are greater than those in Alaska for the first few decades, but growth rate of Ontario stands near maturity declines more rapidly than that of Alaskan stands. Thus, by age 80, Alaskan yields surpass those from Ontario on all sites (table 1) *(40,63,72)*. The range of site index is similar for New England, New York, and the Lake States, 12 to 24 m (40 to 80 ft) at base age 50 years *(22,23)*; and somewhat lower for Alaska, 11 to 20 m (35 to 65 ft) *(40)*, indicating a lower growth potential, probably because permafrost and cold soils limit the growth of birch on many sites.

Paper birch is considered a short-lived species. Trees mature in 60 to 70 years, and few live longer than 140 to *200* years (46). The variety *cordifolia* apparently has a longer life span. Several trees on Mt. Washington in New Hampshire were more than 200 years old; the oldest was 225 (37). Stands appear to last longer in Alaska than in more southerly regions (40).

Mortality is heavy throughout the life of a paper birch stand. Individual trees express dominance early in life. Unless suppressed trees are released early, they soon die. Intermediate trees survive longer but gradually succumb after struggling for years at a low rate of growth (46). Initial stem diameter at the seedling and small sapling stage can be used to predict relative growth potential of trees selected for release. Trees that averaged only 0.8 cm (0.3 in) in diameter when released grew to 5.3 cm (2.1 in) in diameter after 24 years; trees in the same stand that were larger than 2.0 cm (0.8 in) in d.b.h. when released grew to 13.7 cm (5.4 in) in the same time (53).

Rooting Habit-Paper birch is generally a shallow-rooted species. The bulk of the roots are found in the top 60 cm (24 in) of soil; taproots do not form. Rooting depth depends on soil depth and varies among forest stands and from tree to tree within stands (75). High wind will break the bole of paper birch more often than it will uproot the tree. Broken stems generally sprout *(100)*. Rootlets with a primary xylem diameter greater than 25 percent of total diameter tend to become part of the permanent woody root system. Rootlets with a smaller diameter primary xylem are ephemeral (43,102).

Reaction to Competition-Paper birch is classed as a shade-intolerant tree. Among its common associates in the Northeast, only aspen, pin cherry, and gray birch *(Betula populifolia)* are more intolerant. In the natural succession of species, paper birch usually lasts only one generation and then is replaced by more tolerant species (46). When growing in mixture with spruce or spruce-fir, birch often retains a position in the stand, and the stands do not go toward pure spruce climax *(22,67,76)*. Birch persists in some Alaskan spruce stands because of a physical smothering of spruce seedlings by birch foliage, or in other instances, chemical properties of the ashes of birch following fires may inhibit spruce development (67).

In declining old-growth stands of white spruce *(Picea glauca)* growing on flood plains in Alaska, paper birch invades openings created by death and uprooting of the spruce. Mineral soil exposed by the uprooting, and the rotting wood of the fallen trees, provide suitable seedbeds *(28,52,106)*.

In a study of drought response, paper birch saplings had lower leaf conductance values and higher water potential than white oak *(Quercus alba)* growing under the same soil moisture conditions. The birch trees reached water stress conditions sooner than the oak. The birch trees responded to stress by losing leaves, whereas the white oak was not severely stressed by conditions of the study *(30)*.

In a greenhouse study, paper birch seedlings were less tolerant of flooding than river birch *(B. nigra)*. Once flooding treatments ended, paper birch seedlings grew faster and were as large as unflooded controls at the end of the experiment. Flooded river birch seedlings formed adventitious roots; paper birch did not (68).

Because of its intolerance, paper birch often requires release from faster growing species such as aspen or pin cherry that overtop it in the early stages of regeneration (53). Response depends on degree of release. Generally, the greater the release, the greater the growth response of paper birch. Thinnings in sapling and pole stands also yield increased diameter growth of paper birch crop trees in proportion to the degree of release (79). Stands approaching maturity-more than 60 years-seldom respond to thinning *(33,46)*.

Paper birch is a nutrient-sensitive species. Seedling, sapling, pole, and sawtimber-size trees have all responded to fertilizer treatments in recent studies *(15,24,78,80,94,96)*. In a mixed stand, paper birch responded more than quaking aspen but less than big-tooth aspen *(Populus grandidentata)* to additions of nitrogen, phosphorus, and lime *(24,81)*. Response indicated increased stem wood and bark, branches, and foliage *(84,85)*.

Damaging Agents-In the eastern part of its range, large percentages of paper birch were killed or damaged by a condition called birch dieback during the late 1930's and 1940's. Symptoms include dying back of twigs and branches in the crown, loss of vigor, and eventual death over a period of 5 to 6 years. Trees most often damaged were shallow rooted and showed root mortality before crown symptoms. The root mortality was attributed to environmental conditions (75). Many trees sprouted epicormic branches in the lower crown and bole and eventually recovered. The dieback condition has subsided and currently is not considered an important threat to paper birch *(46,63)*.

Postlogging decadence-a condition resembling birch dieback-sometimes develops in residual trees following partial cutting. The older the stand and the heavier the cutting, the more likely this condition. For example, trees left as seed trees in regeneration cuttings are almost certain to decline and die within a few years. The best way to avoid these problems in managed stands of birch is to maintain vitality of trees through periodic thinnings begun at an early age. Also, heavy partial cuttings in mature previously untreated stands should be avoided (63).

The bronze birch borer *(Agrilus anxius)* is the most serious insect pest of the paper birch. Usually it attacks overmature trees or trees in weakened condition. The borer played a secondary role in the

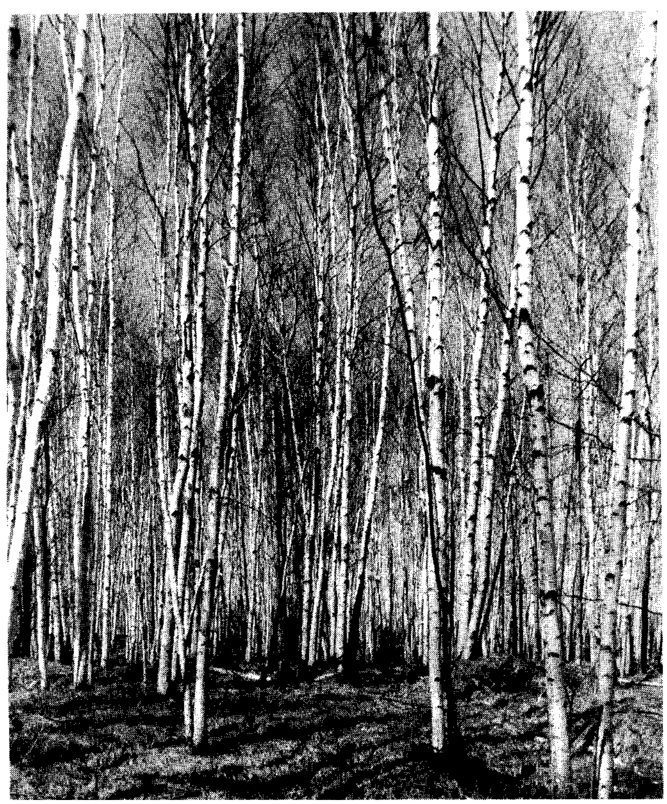


Figure *3-A 35-year-old stand **of** paper birch on a very good site in northern Wisconsin.*

dieback outbreak and undoubtedly caused the death of some trees that otherwise might have recovered. To prevent buildup of this insect, weakened and mature trees should be removed from the stand, and injury to residual trees should be avoided *(21).*

The most serious defoliators of birch are the forest tent caterpillar *(Malacosoma disstria)*, the birch skeletonizer ***(Bucculatrix canadensisella)***, the birch leafminer *(Fenusa pusilla)*, birch leaf-mining sawflies ***(Heterarthrus nemoratus*** and ***Profenusa thomsoni),*** the birch casebearer ***(Coleophora serratella),*** as well as the general forest defoliators-the saddled prominent ***(Heterocampa guttivitta)***, and the gypsy moth ***(Lymantria dispar),*** and in Alaska, the spear-marked black moth ***(Rheumaptera hastata) (101).*** Defoliation alone seldom causes mortality of otherwise healthy trees. Rather, growth rate is reduced and trees become susceptible to other damaging agents, particularly the bronze birch borer, which attacks and causes death of substantial numbers of trees ***(21).*** Cambium miners, such as ***Phytobia pruinosa,*** and ambrosia beetles, such as *Trypodendron* ***betulae*** or ***Xyloterinus politus,*** make injuries that cause defects in paper birch timber but seldom cause the death of trees *(63,88).* The variety ***cordifolia*** may be less susceptible to severe insect attacks than the typical paper birches *(39).*

Micro-organisms that enter the bole of the tree through wounds or branch stubs cause discoloration and decay in paper birch wood. A condition known as red heart is a very common defect in some areas. The wood is darkened in color but may be sound enough for some uses. Principal decay-causing fungi include ***Inonotus obliqua, Phellinus igniarius,*** and ***Pholiota*** spp. (63). Stem cankers that ruin the tree for timber purposes and make it unsightly are often caused by ***Inonotus obliqua*** and ***I. glomeratus*** (87) and ***Nectria galligena.*** The root-rotting fungus ***Armillaria mellea*** infects birch trees, causing cracks at the base of the stem ("collar crack"). Attack by root-rotting fungi can also result in uprooting by the wind (88).

Animals that damage paper birch stands include white-tailed deer, porcupines, moose, and hares. The most serious threat from deer and moose is over-browsing at the seedling stage, which reduces the amount of dominant birch in regenerating stands or impairs the quality of survivors *(46,51).* Porcupines damage larger trees by feeding on the inner bark and girdling large branches in the crown and upper trunk. The yellow-bellied sapsucker pecks rows of holes through the bark; these are the source of entry for discoloration and decay organisms and may cause ring shake (88). If a dense band of holes girdles the stem, all or a major portion of the crown will die, leading to a weakened state that can invite attack by the bronze birch borer or decay organisms. In a Maine study, 51 percent of the paper birch trees damaged by sapsuckers died. Damage by hares and other small mammals is of critical importance to the development of planted seedlings (6). Hares clip or gnaw bark on small birch seedlings causing reduction in birch stocking ***(51).*** Red squirrels may girdle stems by stripping off the bark (46) or wound the tree by biting it to obtain sap (88).

Fire, which is responsible for the establishment of many paper birch stands, is also one of the most serious enemies of established stands. Because the bark of paper birch is thin and highly flammable, even large trees may be killed by moderate fires (46). However, in Alaska, pure birch stands have little fuel available, so fires are not common. Hot crown fires in spruce become slow-burning ground fires when they enter birch stands; the fire may even go out. In extreme drying of deep organic horizons in some birch stands, a hot, slow-moving fire will consume all of the organic matter, leaving the shallow-rooted birch without support. The otherwise undamaged trees soon fall over *(106).* Paper birch is very susceptible to logging damage during partial harvest treatments using mechanical techniques. Up to 53 percent of designated crop trees sustained injuries to root systems, boles, or both during a careful thinning (69).

Near Sudbury, Ontario, air pollution with heavy metals from mining and smelting operations has created a coppice woodland dominated by paper birch and red maple. Seedlings are repeatedly killed back and sprout from the base, creating multi-stemmed stools. On an exposed ridge, l&year-old paper birch sprouts averaged 3.3 m (10.8 ft) in height and 5.8 cm (2.3 in) d.b.h. On a more protected site, 21-year-old paper birch sprouts averaged 5.9 m (19.4 ft) in height and 7.8 cm (3.7 in) d.b.h. (48). In the greenhouse study previously mentioned, fumigation with SO_2 caused partial stomata1 closure, visible foliar injury, and reduced growth rate of both river and paper birch. Stomata1 conductance and SO_2 uptake of flooded seedlings were lower than controls, but SO_2 effects were the same whether flooded or not (68).

People vandalize trees along roadsides and in parks and picnic areas by peeling off strips of the outer papery bark. The trees are seldom killed but always carry unsightly scars. In areas of great scenic value, the exposed inner bark can be painted white to disguise the wound.

Special Uses

Young regenerating stands of paper birch and associated species provide prime browse and cover for deer and moose *(86,91).* Although pin cherry is preferred over birch as a browse species, birch is more important because it is more abundant (70). In Alaska, birch stands produce less browse than aspen but more than willow and alder. Willows are a preferred browse species by Alaskan moose, but birch is preferred to aspen, balsam poplar, or alder. It takes 3 to 5 years following logging, a fire, or other disturbance for production of young trees to begin providing sufficient buds and twigs for browsing animals. Peak browse production occurs from 10 to 16 years after the disturbance. Mature stands have essentially no available browse *(103)*. The browse index for yellow and paper birch in the four northeastern National Forests indicates that birch is preferred 2.5 to almost 5 times more than its abundance would suggest (86).

Paper birch is also an important source of food for birds. The redpoll, pine siskin, and chickadee feed on seeds; the ruffed grouse eats male catkins and buds *(86)*.

The graceful form and attractive white bark of paper birch make it a prized species for ornamental planting and landscaping around homes and public buildings. The main drawback is that bark on young paper birch remains golden or brown in color until about age 10 to 12. For that reason, European birches and some other introduced species that have white bark at earlier ages are more frequently chosen as ornamentals.

Its status as a pioneer species and its adaptability to disturbed sites indicates that paper birch is a prime hardwood species for use in revegetating spoils and other drastically disturbed sites. Paper birch has been planted successfully on acid coal mine spoils. Survival of 2-O planting stock ranged from 58 to 98 percent on spoils with a pH ranging from 3.0 to 4.0 *(25)*.

Paper birch can be tapped in the spring to obtain sap from which syrup, wine, beer, or medicinal tonics can be made. The carbohydrate content of about 0.9 percent consists of glucose, fructose, and sucrose. This contrasts with the 2 to 3 percent sugar found in the sap of sugar maple. Currently only a few small-scale sugaring operations are in Alaska (32). Sap flow season for birch begins and ends later than for maples. Birch syrup contains lower sugar concentrations than maple (302 and 711 g/l) and is more acidic (pH 5.2 and 6.6) *(50)*.

Paper birch has moderately dense wood. Full tree chips can be used in pulp and paper manufacture, other reconstituted uses, and fuel. Branches contain fewer fibers and more vessels than bole-wood. Branch fibers and vessels are 30 to 50 percent shorter and smaller in diameter than those from boles. Pulp from branch-wood is weaker in mechanical strength than pulp from bole-wood but is suitable for paper making *(54,55)*. Equations for estimating biomass of full trees and various components from tree diameter, height, or both, are available *(49,83,89,105)*. As a fuel, caloric values for paper birch did not differ significantly between samples with and without bark, or between bole and branch components when data for samples with and without bark were pooled (66). Paper birch bark has a high fuel value. Of 24 species tested, it had the highest caloric value per unit weight-5740 cal/g (10,331 Btu/lb)—and the third highest per unit volume—3209 cal/cm^3 (360,569 Btu/ft^3) (42).

Genetics

Population Differences

Paper birch consists of a large, very plastic gene pool. There are six recognized varieties: typical paper birch (var. *papyrifera)*, western paper birch (var. *commutata)*, mountain paper birch (var. *cordifolia)*, Kenai birch (var. *kenaica)*, Alaska paper birch (var. *neoalaskana)*, and northwestern paper birch (var. *subcordata)* (58). On the basis of morphological characteristics, seedling growth habits, and chromosome numbers, some authors have suggested that var. *cordifolia* be reinstated to specific rank as *B. cordifolia* *(13)*. Chromosome number varies considerably within the species. The somatic chromosome number for typical paper birch can be either 70 or 84, rarely 56. The chromosome number for var. *cordifolia* is consistently 28, and other varieties may be 42, 56, 70, or 84. Seedlings from the same mother tree typically have two or more chromosome counts (9 through 14, 39). In a comparison of morphological and cytological characteristics of the varieties *commutata* and *subcorduta*, only bark color was consistently different between the two, suggesting that separate variety names were not justified *(11)*.

Within typical paper birch, selections of superior trees have been made on the basis of growth rate, stem form, and other characteristics. In a greenhouse study, seedlings with a plus-tree mother grew significantly taller and larger in basal diameter than trees with “average” mothers. Also, sources from New Hampshire were superior to sources from Michigan, Vermont, Maine, or Eastern Canada, in that order *(77)*.

Hybrids

Hybridization in the birches is common. Paper birch hybridizes naturally with almost every other native species in the genus *(1, 16,58,98)*. The hybrid crosses with yellow (*B. alleghaniensis*), sweet (*B. lenta*), and river (*B. nigra*) birch have not been named. Blue birch (*B.* x *caerulea* or x *caerulea-grandis*) is thought to be a hybrid between grey birch and var. *cordifolia* (12,39). The variety *cordifolia* is thought to be a hybrid of paper and yellow birch (58). The named hybrids are crosses between paper birch and shrub or small tree species, as follows: Yukon birch (*B.* x *eastwoodiae* Sarg. or *B.*x *commixta* Sarg.) with resin birch (*B. glandulosa*); horne birch (*B.* x *hornei* Butler or *B.* x *beeniana* A. Nels.) with dwarf arctic birch (*B. nana*); Sandberg birch (*B.* x *sandbergii* Britton or *B.* x *uliginosa* Dugle) with bog birch (*B. pumila* var. *glandulifera*); and Andrews birch (*B.* x *andrewsii* A. Nels. or *B.* x *piperi* Britton or *B.* x *utahensis* Britton) with water birch (*B. occident&s*).

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