Fagus grandifolia E hrh. American Beech

Fagaceae Beech family

Carl H. Tubbs and David R. Houston

American beech *(Fagus grandifolia)* is the only species of this genus in North America. Although beech is now confined to the eastern United States (except for the Mexican population) it once extended as far west as California and probably flourished over most of North America before the glacial period *(39).* This slow-growing, common, deciduous tree reaches its greatest size in the alluvial soils of the Ohio and Mississippi River Valleys and may attain ages of 300 to 400 years. Beech wood is excellent for turning and steam bending. It wears well, is easily treated with preservatives, and is used for flooring, furniture, veneer, and containers. The distinctive triangular nuts are eaten by people and are an important food for wildlife.

Habitat

Native Range

American beech (fig. 1) is found within an area from Cape Breton Island, Nova Scotia west to Maine, southern Quebec, southern Ontario, northern Michigan, and eastern Wisconsin; then south to southern Illinois, southeastern Missouri, northwestern Arkansas, southeastern Oklahoma, and eastern Texas; east to northern Florida and northeast to southeastern South Carolina. A variety exists in the mountains of northeastern Mexico.

Climate

Within the range of beech, annual precipitation usually is from 760 mm to 1270 mm (30 to 50 in) (39); however, some beech is found in Michigan where precipitation is about 580 mm (23 in), and in Canada where about 640 mm (25 in) fall annually. Precipitation during the growing season varies from *250* mm to 460 mm (10 to 18 in). Beech is a mesophytic species; it uses twice as much water for transpiration and growth processes annually, compared to some drought resistant oaks and even lesser amounts by some pines.

The growing season for beech varies from 100 to 280 days; the species is found in one county in Michigan where the growing season is only 92 days. Mean annual temperatures range from 4" to 21" C (40° to 70° F). Beech can exist under temperature extremes lower than -42" C (-44" F) and 38" C (100" F). Higher than average summer temperatures may be unfavorable for beech growth.

The authors are Research Forester and Research Plant Pathologist, Northeastern Forest Experiment Station, Radnor, PA.

Soils and Topography

Beech is found generally within two principal soil groups: the gray-brown podzolic (Hapludalf) and the laterite (Acrorthox) and is prevalent on podzols; it is seldom found on limestone soils except at the western edge of its range. These soils are contained in the orders Alfisols, Oxisols, and Spodosols. Soils of loamy texture and those with a high humus content are more favorable than lighter soils *(39).* The largest trees are found in the alluvial bottom lands of the Ohio and the lower Mississippi River valleys, and along the western slopes of the southern Appalachian Mountains.

Beech populations frequently are higher on coarse-textured, dry-mesic soils in the northern part of its range (38). In Indiana, beech is more sensitive to reduced soil moisture than is white oak *(Quercus alba),* sugar maple *(Acer saccharum),* American elm *(Ulmus americana),* and slippery elm *(U. rubra).* It will grow on poorly drained sites not subjected to prolonged flooding and may grow where the water table is within 15 cm to 25 cm (6 to 10 in) of the surface. It is markedly less tolerant of such conditions than are red maple *(Acer rubrum)* and sweetgum *(Liquidambar styraciflua).* Beech trees on poorly drained sites have shallower root systems than those on better drained sites (39). Timber stands containing considerable numbers of beech are found on soils ranging from pH 4.1 to 6.0 *(39),* but seldom where pH exceeds 7.0.

Beech is found at low elevations in the North and relatively high elevations in the southern Appalachians. Local soil and climatic factors probably determine whether beech grows at the higher elevations. In the Adirondacks of New York, low temperatures and wind keep beech below 980 m (3,200 ft), in contrast to the southern mountains where on the warmer slopes it grows at elevations up to 1830 m (6,000 ft). At latitudes in the middle of its range, however, beech is more abundant on the cooler and moister northern slopes than on the southern slopes *(39).*

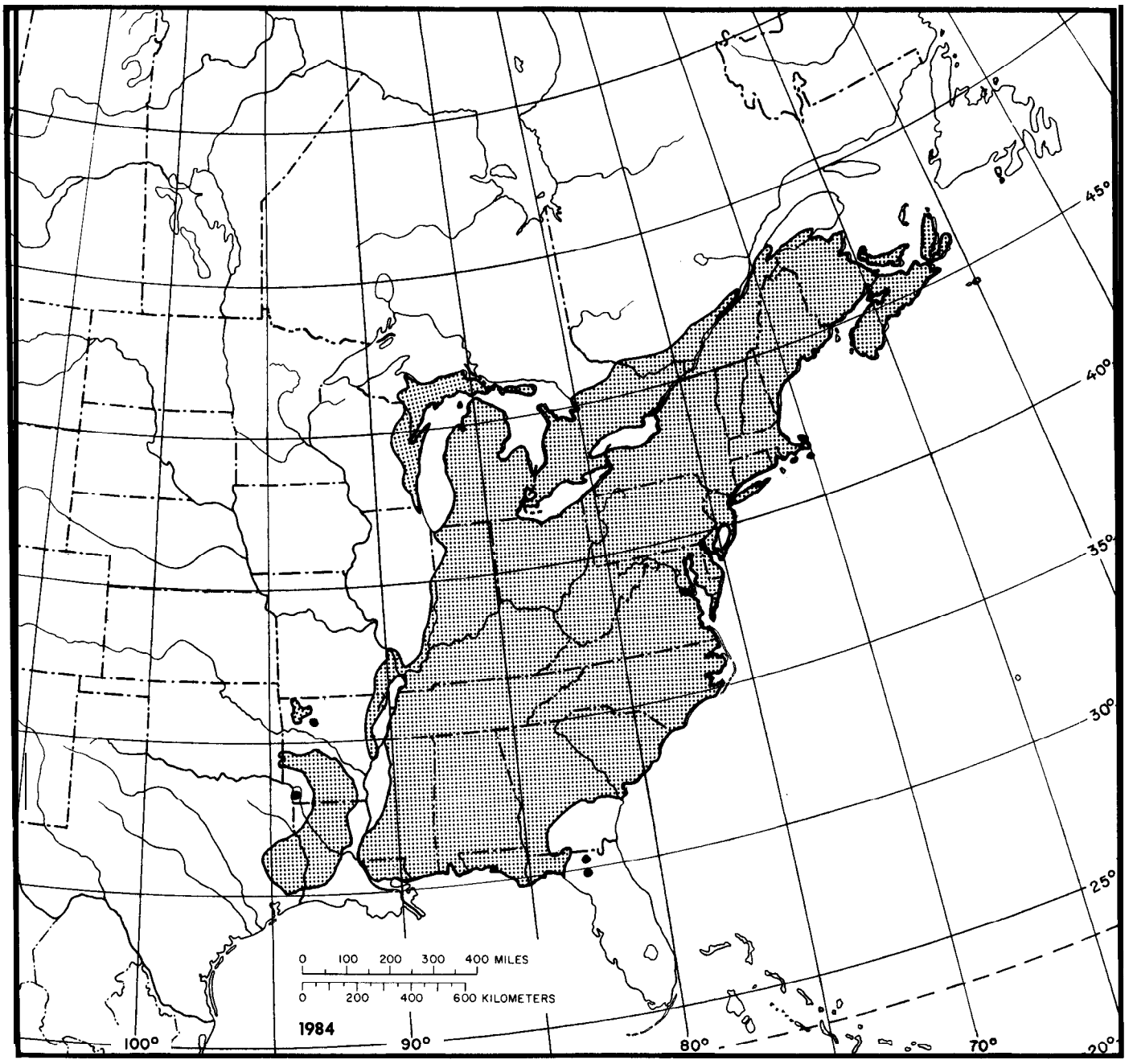

Figure *1-The native range of American beech.*

Associated Forest Cover

Within its wide range in eastern North America, beech is associated with a large number of trees. Some of the principal associates are sugar maple, red maple, yellow birch *(Betula alleghaniensis),* American basswood *(Tilia americana),* black cherry *(Prunus serotina),* southern magnolia *(Magnolia grandiflora),* eastern white pine *(Pinus strobus),* red spruce *(Picea rubra),* and several hickories *(Carya* spp.) and oaks *(Quercus* spp.). Beech is included in 20 forest cover types and is a major component in the following three *(5):* Sugar Maple-Beech-Yellow Birch (Society of American Foresters Type 25), Red Spruce-Sugar Maple-Beech (Type 31), and Beech-Sugar Maple (Type 60). Beech is a minor species in 17 other cover types.

Life History

Reproduction and Early Growth

Flowering and Fruiting-In the Northern and Central States, beech flowers appear in late April or early May when the leaves are about one-third grown; the species is monoecious. The flowers are quite vulnerable to spring frosts. Male flowers occur in long-stemmed heads; female flowers in clusters of two to four *(40)*. Beechnuts require one growing season to mature and they ripen between September and November. Two or (rarely) three nuts may be found within a single bur. The first nuts to fall are usually wormy or aborted.

Seed fall begins after the first heavy frosts have caused the burs to open and is completed within a few weeks. Some empty burs remain on the trees throughout the winter.

Seed Production and Dissemination-Beech ordinarily begins to produce a substantial amount of seeds when about 40 years old, and by the time it is 60 years old may produce large quantities. Good beech seed crops are produced at 2- to B-year intervals (40).

Beech seeds, averaging about 3,500/kg (1,600/lb), are relatively heavy. Most of the seeds simply drop to the ground under the parent trees. Rodents may carry some of them short distances and on steep terrain a few may roll down slopes, but dispersal is quite restricted. Bluejays may transport many beech seeds several kilometers *(16,17)*.

Seedling Development-Beech seeds germinate from early spring to early summer. Germination is epigeous and chilling is required to break dormancy. On either mineral soil or leaf litter, germination is good, but on excessively wet sites it is poor. Both germination and survival tend to be better on mor humus than on mull humus soil (39,401.

Beech seedlings develop better under a moderate canopy or in protected small openings than they do on larger open areas where the surface soil may dry out below the depth of the shallow roots. Height growth of seedlings is about the same in dense (87 percent) or moderate (55 percent) shade, but total dry weight and root development are greatest under moderate shade. Height growth, dry weight, and root development in the open are less than in shade (25). Seedlings are found in large numbers beneath even the densest stands, but under such conditions their growth is slow. Beech reproduction can start under, and come through, fern and raspberry cover.

Dormancy of beech seedlings can be broken in spring and growth can be prolonged in fall by supplemental light. Decreasing day length plays the major role in inducing dormancy in the fall, but day length may be secondary to temperature in controlling resumption of growth in the spring. That is, day length probably becomes adequate for growth to resume in the spring before temperatures are high enough for growth to occur. Temperature, therefore, exerts the final control over growth resumption.

Beech continues growing all winter in a greenhouse when daylight is supplemented by continuous artificial light.

The height of beech seedlings growing in the intense competition of a virgin hemlock-hardwood stand in northern Pennsylvania (39) was as follows:

Age	Total height	
yr	*m*	*ft*
6	0.3	1
10	0.6	2
14	0.9	3
17	1.2	4
18	1.4	4.5
20	1.5	5
22	1.8	6
25	2.1	7

When forest stands are heavily cut, beech reproduction tends to grow more slowly than that of most associated hardwood species. This is especially true in clearcuttings. Here the beech reproduction may be overtopped by less tolerant species, such as the birches and white ash *(Fraxinus americana),* that respond vigorously to increased light. A number of studies have shown that heavy cutting or clearcutting results in fewer beech in the new stand than in the old (39). Repeated clearcutting on short rotations may nearly eliminate beech. Under partial cuttings, especially single-tree selection cuttings, intolerant species offer little competition and the tolerant beech reproduction is able to develop. The beech may be further favored by its virtual immunity to deer browsing.

Vegetative Reproduction-Beech sprouts well from the stumps of young trees, but this ability diminishes after trees reach 10 cm (4 in) in d.b.h. Sprouts from stumps 25 cm to 38 cm (10 to 15 in) in diameter usually are short lived and do not attain tree stature. Numerous sprouts may develop on the trunk of beech immediately below a wound, and from the tops of stumps; here adventitious buds develop in callus tissue of the cambial region.

Beech trees may develop large numbers of root sprouts or suckers. Studies *(30)* have shown that

reproduction is almost exclusively by suckering in the "beech gaps" and is abundant in the Adirondack Mountains of New York, in Maine *(13),* and in many other areas, often those near the northern and western limits of its range *(11,42)* where environments are severe (27). Suckering is stimulated only slightly by removal of the stem *(18).* Injury to roots appears to be necessary for the initiation of root sprouts in beech (19). Root sprouts arise from adventitious buds that form within callus tissues associated with wounds. Experimental injuries to roots in November resulted in fewer sprouts than did injuries inflicted in spring *(20).* Sometimes root sprouts develop where no apparent injury has occurred (39). There were relatively more root sprouts on southerly slopes in areas where freeze-thaw action tended to injure shallow or exposed roots and stimulate sprout formation, and where late spring frosts tended to injure or kill young seedlings. In Ohio, seedling regeneration was positively associated with northerly exposures and root sprout regeneration with southerly exposures *(11).*

In an undisturbed stand of mature beech in the Adirondacks, 1,730 to 2,220 root sprouts per hectare (700 to 900/acre; 7 to 12/tree) were counted (39). Casual observations elsewhere indicate that the number per tree may greatly exceed this figure.

Root sprouts can develop into desirable trees. Isozyme genetic studies have shown that some groups of overstory beech trees with similar phenotypic traits are clones *(14).* Sometimes root sprouts are ephemeral. In one reproduction study, made after a 60-year-old stand of beech was cut, all of the root sprouts died within 4 years. On the other hand, the trees in a 40-year-old beech stand of sprout origin averaged 10 cm (4 in) in d.b.h. and 11.6 m (38 ft) in height.

Beech limbs root in a single year when layered. Interspecific root grafting is common.

Sapling and Pole Stages to Maturity

Growth and Yield-Beech's period of radial growth may continue for 80 to 89 days in the Georgia Piedmont and for approximately 60 days in Indiana (39). Annual height growth of beech saplings is complete in about 60 days; 90 percent of this growth occurs between May 10 and June 10. American beech has a lower site index than any associated hardwood in the northern Lake States.

The radial growth period is influenced by available soil moisture. Under normal conditions, it may end in the middle of July, but drought may end it in mid-June. A few individual trees may continue their growth into August and September. In dry years, annual rings may not grow in the basal sections of some beech trees. In general, radial growth of beech begins when the leaves are fully expanded.

Table l-Characteristics of American beech growing in the Lake States

Age	D.b.h.	Height	Volume
yr	*cm*	*m*	m^3
20	2	4.0	—
40	6	8.5	—
60	10	11.9	0.03
80	14	14.6	0.10
100	18	17.4	0.22
150	29	22.9	0.76
200	40	25.6	1.58
250	51	26.8	2.69
yr	*in*	*ft*	ft^3
20	0.7	13	—
40	2.3	28	—
60	3.8	39	1.0
80	5.4	48	3.7
100	7.1	57	7.9
150	11.5	75	27.0
200	15.7	84	56.0
250	19.9	88	95.0

The annual diameter increment of beech of pole and small saw-log size averages from around 1.8 to 2.3 mm (0.07 to 0.09 in) in undisturbed second-growth stands to 3.8 to 4.8 mm (0.15 to 0.19 in) in trees released by partial cuttings *(35,39).* Annual growth of poles for 5 years after heavy release, leaving from 1.1 to 4.6 m^2/ha (5 to 20 ft^2/acre) of basal area, ranged from 5.6 mm (0.22 in) to 7.6 mm (0.30 in); growth was better in the most heavily stocked stands and on trees with good crown development (26).

Under optimum conditions, beech trees may become 37 m (120 ft) high; however, they generally average 18 to 24 m (60 to 80 ft). Growth data for beech in the Lake States are shown in table 1.

Among 12 broad-leaved species rated according to their longevity, beech was exceeded only by white oak and sugar maple. Beech trees older than 366 years have been found in Pennsylvania. The distribution of numbers of trees by age is "J" shaped, typical of tolerant long-lived species *(21).* One of the largest beeches on record, growing in Michigan, is 135 cm (53.2 in) in d.b.h., 49 m (161 ft) tall, and has a crown *32* m (105 ft) wide.

Beech trees prune themselves in well-stocked stands. Open-grown trees, however, develop short, thick trunks with large, low, spreading limbs ter-

minating in slender, somewhat drooping branches that form a broad, round-topped head.

Beech trees that have been injured or suddenly exposed by stand cuttings often develop epicormic branches. In one stand where 65 percent of the basal area had been cut, 40 percent of the remaining beech trees had epicormic branches 5 years later, whereas in a similar but uncut stand, only 17 percent of the trees had such branches (39). Epicormic branching of beech trees has also been observed after glaze damage and after low-temperature injury (27). One report on winter injury showed epicormic branches to be restricted largely to trees with d.b.h. of 10 cm (4 in) or less (2).

Rooting Habit-Young seedlings have a taproot that gives way to a heart root system as the tree matures *(41).* The root system is generally shallow but may penetrate to 1.5 m (5 ft) or more in deep soils. The fine roots form a dense mat in our soil types. Beech root systems are more shallow than the associated yellow birch and sugar maple. Few tree species are less tolerant of flooding during the growing season than American beech.

Root exudates of beech contain more organic acids than those of sugar maple or yellow birch.

Reaction to Competition-Beech is classed as very tolerant of shade. In some parts of its range, beech is the most tolerant species. Its tolerance is partly due to its very low respiration rate (24) and the quick response of the stomata, which open when light suddenly increases and rapidly close when light intensity diminishes. Beech stomata are more responsive than those of red maple, red oak *(Quercus rubra),* or yellow-poplar *(Liriodendron tulipifera),* which are less tolerant (43). On very poor soils or in very cold climates, beech may be less tolerant. The tolerances of beech and associated sugar maple are about the same *(25),* although locally one species or the other may predominate in the forest understory. Factors other than the ability to endure shade appear to govern the relative success of beech and its common tolerant competition, sugar maple, eastern hemlock *(Tsuga canadensis),* and balsam fir *(Abies balsamea).* Beech may be more competitive under somewhat adverse site and climate conditions (39).

Beech and sugar maple are recognized as climatic climax species in the northern hardwood types of the Northeast, Lake States, and Appalachian Mountains. In the Southeast, relict areas of beech suggest that an original maple-beech association has been displaced by the once subclimax oak-hickory community.

Damaging Agents-In regions with low winter temperatures, long frost cracks often appear in the tree trunks. These cracks are sometimes superficial but sometimes extend deep into the bole. In the Northeast, beech has been damaged or killed by temperatures of -40" to -45" C (-40" to -50" F) preceded by severe droughts (39). Injured trees died the following summer and winter. Beech can be severely damaged by late spring frosts.

In a Kentucky study of effects of flooding, beech was one of the more sensitive species. Beech trees were killed by 2 weeks of submergence of their root crowns in summer. An 18-day period of flooding in winter had no apparent adverse effect, however.

Beech's susceptibility to glaze-storm breakage is no greater than that of its associated hardwoods and may be somewhat less than the average for a mixed stand (39). Except on shallow soils, beech is rather windfirm.

The thin bark of beech renders it highly vulnerable to injury by fire (large shallow roots are especially vulnerable), sunscald, logging, pruning, or disease. When large branches are broken they heal comparatively slowly (38) and serve as entrance courts for a host of decay fungi *(12,32).*

More than 70 decay fungi (a record for a hardwood species) have been reported for beech *(12).* The most important include *Daedalea unicolor, Ganoderma applanatum, Fomes fomentarius, Phellinus igniarius, Hericium erinaceus, H. coralloides, Steccherinum septentrionale, Inonotus glomeratus,* and *Ustilina vulgaris.* The shoestring fungus, *Armillaria* sp., the most important root pathogen, attacks and girdles roots of weakened trees. Beech roots are also parasitized by the broomrapes, *Conopholis americana* and *Epifagus virginiana.* The latter, beech drops, is specific to beech *(8,34).*

The thinness of beech bark also makes it vulnerable to an unusually large number of sucking insects, including the beech blight aphid, *Fagiphagus imbricator,* and the giant bark aphid, *Longistigma caryae.* Continuous heavy outbreaks of the oystershell scale, *Lepidosaphes ulmi,* have resulted in severe crown dieback and even in the death of entire stands *(1). Xylococculus betulae,* another scale, causes roughened spots on stems of young trees and is especially devastating to the sprout thickets that have emerged in the aftermath of beech bark disease (fig. 2), the most serious problem of this species *(13,31).*

Beech bark disease is initiated when yet another scale insect, the beech scale, *Cryptococcus fagisuga,* attacks the bark of beech trees and renders it susceptible to bark canker fungi of the genus *Nectria (3,33).* The insect component of this *scale-Nectria*

Figure 2—The American beech tree on the left is free of the beech bark disease; the two trees on the right are infected severely.

"complex" was introduced to Nova Scotia from Europe around 1890 and is now found throughout New England, New York (15) and northern Pennsylvania (37). In 1981, a 70,000-acre infestation was detected in northeastern West Virgina, many miles south of the nearest previously known infestation *(28)*. More recently, the disease has been reported as far west as Toronto, Ontario, and the scale is now present in northeastern Ohio and northwestern Virignia (29). In North America, *Nectria coccinea* var. *faginata* is the fungus most commonly associated with the disease in the Maritime Provinces, New England, and northern New York. In western Pennsylvania, West Virginia, and some New York stands however, N. *galligena* is the predominant associated species. As the disease and forest interact for the first time, mortality may be so severe that a large proportion of the big, mature beech trees are killed. Mortality is now especially high in some southern and western areas of the Adirondack Mountain region. The percent stocking of beech was reported (7) to remain the same after the killing front of the beech bark disease moved through a managed stand; the disease mainly affected the larger trees. Although such mortality is rare in stands emerging in the aftermath of the disease, severe defect may be caused by the now-endemic causal complex together with *Xylococculus betulae (13)*.

Defoliation by insects can occasionally be a serious problem *(1)*. The most damaging is the saddled prominent, *Heterocampa guttiuitta,* although the forest tent caterpillar *(Malacosoma disstria),* gypsy moth *(Lymantria dispar),* fall cankerworm *(Alsophila pometaria),* and the Bruce spanworm *(Operophtera bruceata)* occasionally cause heavy defoliation in local areas. Insect defoliation often renders trees susceptible to attack by the shoestring root fungus.

Beech is seldom severely browsed by white-tailed deer. When other, more desirable tree species are available, beech is usually nipped only sparingly (36).

Special Uses

Beech mast is palatable to a large variety of birds and mammals, including mice, squirrels, chipmunks, black bear, deer, foxes, ruffed grouse, ducks, and bluejays. Beech is the only nut producer in the northern hardwood type. Beech wood is used for flooring, furniture, turned products and novelties, veneer, plywood, railroad ties, baskets, pulp, charcoal, and rough lumber. It is especially favored for fuelwood because of its high density and good burning qualities.

Creosote made from beech wood is used internally and externally as a medicine for various human and animal disorders. (It is important to note that coal tar creosote, the kind used to protect wood from rots, is highly toxic to humans.)

Genetics

Fagus grandifolia Ehrh. is the only type species of American beech now recognized in North America *(9,10,23)*. Some botanical authorities hold that Northern and Southern beeches vary, and have described the southern form as ***F. grandifolia*** var. *caroliniana* (Loud.) Fern. & Rehd., Carolina beech *(4,6)*. A previously named species in the mountains of Mexico (39) has been renamed a variety, *F. grandifolia* var. *mexicana* (Martinez) Little (22).

Literature Cited

1. Baker, Whiteford L. 1972. Eastern forest insects. U.S. Department of Agriculture, Miscellaneous Publication 1175. Washington, DC. 642 p.
2. Cain, Robert L. 1942. Winter killing of beech on the Huntington Forest. Thesis, New York State College of Forestry, Syracuse University. 19 p.
3. Ehrlich, J. 1934. The beech bark disease, a *Nectria* disease of *Fagus,* following *Cryptococcus fagi* (Baer.). Canadian Journal of Research 10:493–692.
4. Elias, Thomas S. 1971. The genera of Fagaceae in the southeastern United States. Journal of the Arnold Arboretum 52:159–195.
5. Eyre, F. H., ed. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC. 148 p.
6. Fernald, Merritt Lyndon. 1950. Gray's manual of botany. 8th ed. American Book Co., New York. 1,632 p.
7. Filip, Stanley M. 1978. Impact of beech bark disease on uneven-age forest management of a northern hardwood forest. USDA Forest Service, General Technical Report NE-45. Northeastern Forest Experiment Station, Broomall, PA. 7 p.
8. Gill, L. S. 1953. Broomrapes, dodders, and mistletoes. *In* Plant diseases. p. 73-77. U.S. Department of Agriculture, Yearbook of Agriculture 1953. Washington, DC.
9. Gleason, Henry A. 1952. New Britton and Brown illustrated flora of northeastern United States and adjacent Canada. 3 vols. New York Botanical Garden, Hafner Press, New York.
10. Gleason, Henry A., and Arthur Cronquist. 1963. Manual of vascular plants of northeastern United States and adjacent Canada. D. Van Nostrand, Princeton, NJ. 810 p.
11. Held, M. E. 1980. An analysis of factors related to sprouting and seeding in the occurrence of *Fagus grandifolia* Ehrh. in the eastern deciduous forest of North America. Thesis (Ph.D.), Ohio University, Athens. 112 p.
12. 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.
13. Houston, D. R. 1975. Beech bark disease: the aftermath forests are structured for a new outbreak. Journal of Forestry 73(10):660–663.
14. Houston, D. R., and D. B. Houston. 1987. Resistance in American beech *to Cryptococcus fagisuga:* Preliminary findings and their implications for forest management. *In:* Proceedings, 30th Northeastern Forest Tree Improvement Conference, Orono, Maine, July 22–24, 1986. p 105-116.
15. Houston, D. R., E. J. Parker, and D. Lonsdale. 1979. Beech bark disease: patterns of spread and development of the initiating agent *Cryptococcus fagisuga.* Canadian Journal of Forest Research 9:336–343.
16. Johnson, W. C., and C. S. Adkisson. 1985. Dispersal of beech nuts by bluejays in fragmented landscapes. American Midland Naturalist 113(2):319–324.
17. Johnson, W. C., and C. S. Adkisson. 1986. Airlifting the oaks. Natural History (Oct.): 41-46.
18. Jones, R. H. 1986. Initiation, spatial distribution, and demography of root sprouts in American beech *Fagus grandifolia* Ehrh.). Ph.D. Thesis, SUNY College of Environmental Science and Forestry, Syracuse, NY. 142 p.
19. Jones, R. H., and D. J. Raynal. 1986. Spatial distribution and development of root sprouts in *Fagus grandifolia.* American Journal of Botany 73(12):1723–1731.
20. Jones, R. H., and D. J. Raynal. 1988. Root sprouting in American beech *(Fagus grandifolia* Ehrh.): effects of root injury, root exposure and season. Forest Ecology and Management.(In Press).
21. Leak, W. B. 1975. Age distribution in virgin red spruce and northern hardwoods. Ecology 56(6):1451–1454.
22. Little, Elbert L., Jr. 1965. Mexican beech, a variety of *Fagus grandifolia.* Castanea 30:167–170.
23. Little, Elbert L., Jr. 1979. Checklist of United States trees (native and naturalized). U.S. Department of Agriculture, Agriculture Handbook 541. Washington, DC. 375 p.
24. Loach, R. 1967. Shade tolerance in tree seedlings. I. Leaf photosynthesis and respiration in plants raised under artificial shade. New Phytology 66(1967):607–621.
25. Logan, K. T. 1973. Growth of tree seedlings as affected by light intensity. V. White ash, beech, eastern hemlock and general conclusions. Department of Environment, Canadian Forestry Service Publication 1323. Ottawa, ON. 12 p.
26. Marquis, David A. 1941. Survival, growth, and quality of residual trees following clearcutting in Allegheny hardwood forests. USDA Forest Service, Research Paper NE-477. Northeastern Forest Experiment Station, Broomall, PA. 9 p.
27. Mercer, E. P. 1969. Variation in the morphology and ecology of *Fagus grandifolia* Ehrh. in North Carolina. Thesis (MS.), North Carolina State University, Raleigh.
28. Mielke, M. E., C. Haynes, and W. L. MacDonald. 1982. Beech scales and *Nectria* galligena on beech in the Monongahela National Forest, West Virginia. Plant Disease Reporter 66(9):851–852.
29. Mielke, M. E., D. B. Houston, and D. R. Houston. 1985. First report of *Cryptococcus fagisuga,* initiator of beech bark disease, in Virginia and Ohio. (Disease Note) Plant Disease 69:905.
30. Russell, N. H. 1953. The beech gaps of the Great Smoky Mountains. Ecology 34:366–374.
31. Shigo, A. L. 1962. Another scale insect on beech. USDA Forest Service, Station Paper 169. Northeastern Forest Experiment Station, Broomall, PA. 13 p.
32. Shigo, A. L. 1964. Organism interactions in the beech bark disease. Phytopathology 54:263–269.

33. Shigo, A. L. 1965. The pattern of decays and discolorations in northern hardwoods. Phytopathology 55(6):648–652.
34. Small, J. K. 1933. Manual of southeastern flora. Published by author. New York. 1554 p.
35. Solomon, Dale S. 1977. The influence of stand density and structure on growth of northern hardwoods in New England. USDA Forest Service, Research Paper 362. Northeastern Forest Experiment Station, Broomall, PA. 13 p.
36. Tierson, W. L. 1967. Influence of logging, beech control, and partial dyer control on northern hardwood reproduction. Thesis (M.S.), State University of New York, College of Environmental Science and Forestry, Syracuse.
37. Towers, Barry. 1978. Forest pest conditions in Pennsylvania. Pennsylvania Bureau of Forestry, Division of Forest Pest Management, Annual Report. Harrisburg. 23 p.
38. Tubbs, C. H. 1978. Northern hardwood ecology. *In* Proceedings, 1978 Joint Convention of the Society of American Foresters and the Canadian Institute of Forestry. p. 329-333.
39. U.S. Department of Agriculture, Forest Service. 1965. Silvics of forest trees of the United States. H. A. Fowells, comp. U.S. Department of Agriculture, Agriculture Handbook 271. Washington, DC. 762 p.
40. U.S. Department of Agriculture, Forest Service. 1974. Seeds of woody plants in the United States. C. S. Schopmeyer, tech. coord. U.S. Department of Agriculture, Agriculture Handbook 450. Washington, DC. 883 p.
41. U.S. Department of Agriculture, Forest Service. 1980. Rooting habits of selected commercial tree species of the eastern United States-a bibliography. Penninah Smith and Leanna Every, comp. Bibliographies and Literature of Agriculture 10. Washington, DC. 59 p.
42. Ward, R. T. 1961. Some aspects of regeneration habits of the American beech. Ecology 42:828–832.
43. Woods, David B., and N. C. Turner. 1971. Stomata1 response to changing light by four tree species of varying shade tolerance. New Phytology 70(1971):77–84.