# *Carpinus caroliniana* Walt.     American Hornbeam

**Betulaceae     Birch family**

**F. T. Metzger**

American hornbeam *(Carpinus caroliniana),* also called blue-beech, ironwood, water-beech, or lechillo (Spanish), is a small slow-growing short-lived tree in the understory of eastern mixed hardwood forests. The short, often crooked trunk covered with a smooth slate gray bark is characteristically ridged, resembling the muscles of a flexed arm. The wood is close-grained, very hard, and heavy but little used because such a small tree is rarely converted into sawed products.

## Habitat

### Native Range

American hornbeam (figs. 1, 2) is native to most of the eastern United States and extends into Canada in southwest Quebec and southeast Ontario. Its western limit is just beyond the Mississippi River from north-central Minnesota to the Missouri River, where it ranges southwestward into much of the Ozark and Ouachita Mountains and eastern Texas. It grows throughout much of the South but is absent from the Mississippi River bottom land south of Missouri, the lowermost Gulf Coastal Plain, and the southern two-thirds of Florida. Northward along the east coast, it is not found in the New Jersey pine barrens, much of Long Island, Cape Cod, northern and eastern Maine, and the White and Adirondack Mountains. It is found in central and southern Mexico, Guatemala, and western Honduras.

### Climate

The climate varies greatly from north to south in this species habitat. Mean annual precipitation ranges from 710 mm (28 in) in Minnesota to 1570 mm (62 in) along the Gulf Coast. Most precipitation occurs during the growing season, April through September. Mean January temperatures range from -13" C (8° F) to 16" C (60" F) and the mean July temperatures range from 16" C (60" F) to 29" C (84" F). Frost-free periods are from 80 to 320 days.

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### Soils and Topography

Best growth and development of American hornbeam occurs on rich, wet-mesic sites, but it is not restricted to such sites and can tolerate a wide variety of conditions. Habitat requirements and tolerances of the species are similar across its range.

Soils primarily associated with the species are in the orders Alfisols, Ultisols, and Inceptisols but American hornbeam also occurs on Entisols, Spodosols, Histosols, and Mollisols.

The best sites may be characterized as having abundant soil moisture but sufficient drainage to prevent saturation and poor aeration of the soil during the growing season *(4,51).* Typically, the best sites are alluvial or colluvial soils in the transition zone between mesic and wet areas *(46),* as near lakes and swamps *(35),* on well-drained terraces of rivers *(32,45),* terraces or steep slopes of minor streams with some gradient *(39),* coves, ravine bottoms *(33),* and rises in lowlands (40). Surface soil layers are somewhat poorly to well drained but the subsoil may not be as well drained, may have a high fluctuating water table, or may be of heavier texture. Soil water-holding capacity usually is high *(15,49).* Upper soil horizons are primarily loams or of loam-influenced textures. Nutrients and organic matter tend to accumulate on these sites *(36),* and calcium and magnesium in particular are normally more abundant than in surrounding soils (13). Soil pH tends to be acidic-normally from 4.0 to 5.6but can be as high as 7.4 (35).

The species also grows well on wetter sites, such as hardwood swamps on mineral soils or mucks *(3,37).* The key appears to be improving soil moisture conditions through the growing season because the species is only moderately tolerant of flooding (14). It is eliminated from sites inundated more than 25 percent of the time (24). Accordingly, it is absent or rare on the wettest sites, such as lower floodplain terraces, permanently inundated areas, and swamps with peat soils.

American hornbeam also grows, to a lesser extent, on mesic to xeric sites *(5,19).* In Florida and Ontario the species occurs more often on dry-mesic than on mesic or xeric sites. The dry-mesic sites in Ontario have a higher soil moisture retaining capacity than the others (35). In hilly terrain it is found most frequently on north aspects but also grows on ridge tops and on south aspects where subirrigation of the site improves soil moisture (51).
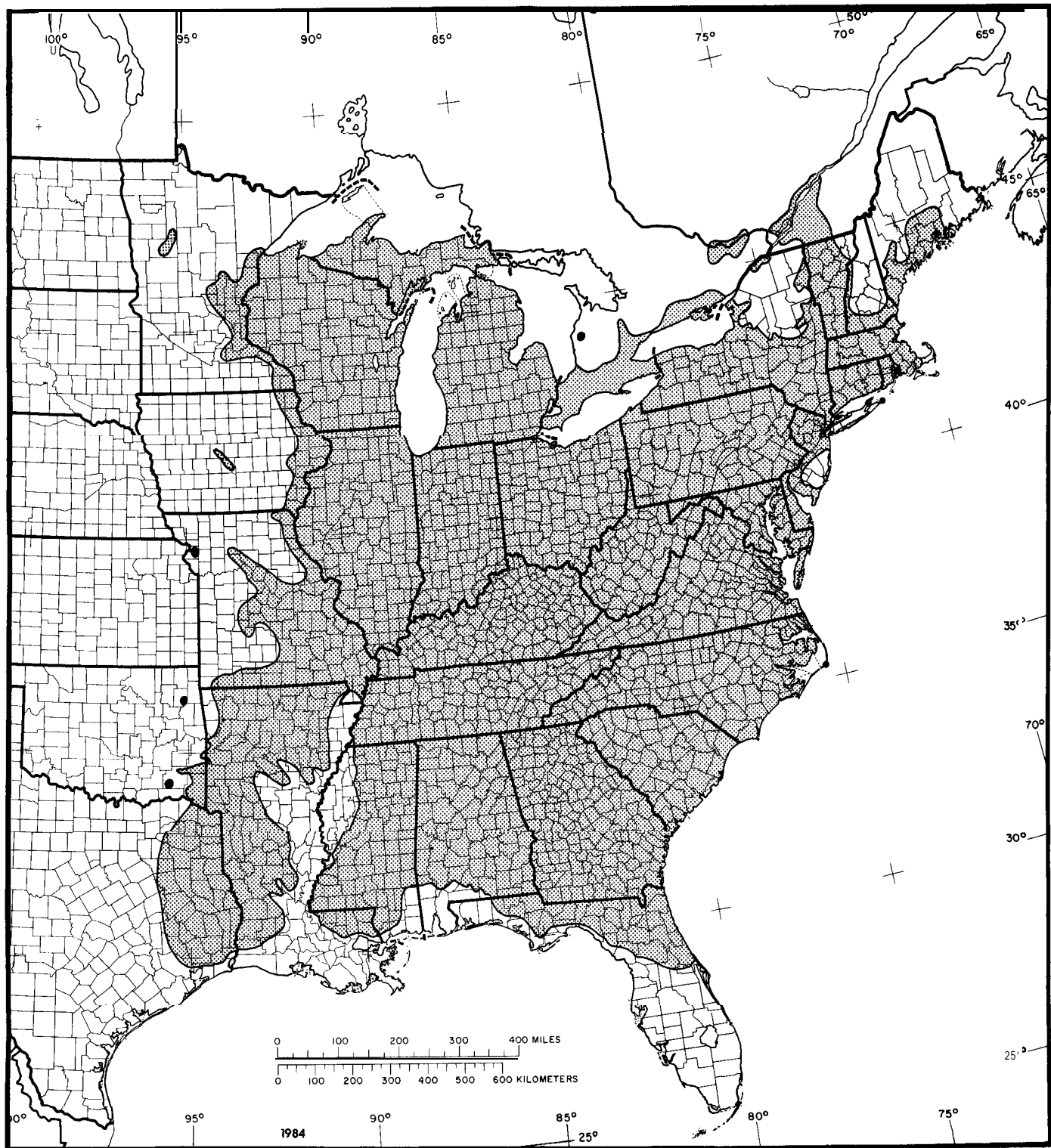
**Figure** *1-The native range of American hornbeam.*

**Figure** *S-American hornbeam.*

The upper altitudinal limit of American hornbeam is 910 m (3,000 ft) in the Great Smoky Mountains, but it is much more common at about 490 m (1,600 ft) (59).

Concentrations of potassium, nitrogen, calcium, and phosphorus in the foliage of the species are low in comparison to those of other species (2). American hornbeam leaf litter, on the other hand, has high concentrations of these nutrients in relation to other species (57).

## Associated Forest Cover

American hornbeam is typically an understory species and only rarely occurs in the overstory or dominates a stand. It is present in the following forest cover types (Society of American Foresters) (22): Northern Forest Region, Black Cherry-Maple (Type 28), Beech-Sugar Maple (Type 60); Central Forest Region, White Oak-Black Oak-Northern Red Oak (Type 52), White Oak (Type 53), Northern Red Oak (Type 55), River Birch-Sycamore (Type 61), Pin Oak-Sweetgum (Type 65); Southern Forest Region, Swamp Chestnut Oak-Cherrybark Oak (Type 91), Sweetgum-Yellow-Poplar (Type 87).

American hornbeam is found in a wide variety of forest communities and with many tree species because its habitat frequently is an ecotone in which species from wet and mesic sites intergrade. In the North, it is a minor component of many different types, infrequently becoming the first or second most abundant tree species in the subcanopy layer (32). It is associated with northern hardwoods and their wet site variants. Sugar maple *(Acer saccharum)* and/or American beech *(Fagus grandifolia)* are dominant in many situations but may be replaced by eastern hemlock *(Tsuga canadensis),* yellow birch *(Betula alleghaniensis),* red maple *(Acer rubrum),* American elm *(Ulmus americana),* silver maple *(Acer saccharinum),* and black ash *(Fraxinus nigra)* on wetter sites.

In the central portion of its range, American hornbeam also is a minor component of stands. Species dominant in northern stands also dominate here along with white *(Quercus alba),* black *(Q. velutina),* northern red *(Q. rubra),* scarlet *(Q. coccinea),* pin *(Q. palustris),* and chinkapin *(Q. muehlenbergii)* oak; bitternut hickory *(Carya cordiformis);* black tupelo *(Nyssa sylvatica);* sweetgum *(Liquidambar styraciflua);* yellow-poplar *(Liriodendron tulipifera);* river birch *(Betula nigra);* and basswood *(Tilia americana).*

The species attains its greatest prominence in southern stands, yet remains a member of the understory. In a number of areas it is the most numerous of all tree species in the stand (36,40). It is found in southern mixed hardwood and loblolly pine *(Pinus taeda)* forests. Overstory species that frequently dominate these stands are sweetgum, water *(Quercus nigra),* white, laurel *(Q. laurifolia),* willow *(Q. phellos),* cherrybark *(Q. falcata* var. *pagodifolia),* and swamp chestnut *(Q. prinus)* oak, American beech, black tupelo, red maple, loblolly pine, southern magnolia *(Magnolia grandiflora),* and yellow-poplar.

The species is also an important member of some nonforest vegetative types in the Northeast. It is an early migrant and forms pure stands in moist old fields (61) and grows in persistent shrub communities in old pastures on hilltops and more exposed hilltops (20).

Understory tree species associated with American hornbeam throughout much of its range include eastern hophornbeam *(Ostrya uirginiana),* flowering dogwood *(Cornus florida),* witch-hazel *(Hamamelis virginiana),* the serviceberries *(Amelanchier* spp.), and speckled alder *(Alnus rugosa).* Northern associates are striped *(Acer pensylvanicum)* and mountain maple *(A. spicatum).* Red mulberry *(Morus rubra),* pawpaw *(Asimina triloba),* and eastern redbud *(Cercis canadensis)* are common associates from the Central States southward. In the South, associated species include sourwood *(Oxydendrum arboreum),* possumhaw *(Ilex decidua),* American holly *(Ilex*

*opaca),* winged elm *(Ulmus alata),* sweetbay *(Magnolia virginiana),* water-elm *(Planera aquatica),* parsley hawthorn *(Crataegus marshallii),* river-flat hawthorn *(C. opaca),* common persimmon *(Diospyros virginiana),* and Carolina laurelcherry *(Prunus caroliniana).*

Shrub species associated with American hornbeam throughout its range include spicebush *(Lindera benzoin)* and southern arrowwood *(Viburnum dentatum).* In the northern half of its range, American hornbeam is associated with mapleleaf viburnum *(Viburnum acerifolium),* redberry elder *(Sambucus pubens),* common winterberry *(Ilex verticillata),* and alternate-leaf dogwood *(Cornus alternifolia).* In the southern half of its range it is associated with devils-walkingstick *(Aralia spinosa),* beautyberry *(Callicarpa americana),* Virginia-willow *(Itea virginica),* southern bayberry *(Myrica cerifera),* sweetleaf *(Symplocos tinctoria),* and tree sparkleberry *(Vaccinium arboreum).*

## Life History

### Reproduction and Early Growth

**Flowering and Fruiting-The** species is monoecious, with male and female catkins borne separately on the same tree and first appearing in the spring concurrently with leaf-out. Catkins are green to brown with red on the scales. Staminate catkins are pendant from lateral, short branches and 3 to 4 cm (1.25 to 1.5 in) long. Pollen matures and is wind disseminated in the spring (63). Pistillate catkins are 13 to 19 mm (0.5 to 0.75 in) long and occur in spikelike groups at the terminus of leafy shoots. Flowering occurs between March 20 and May 6 in the Southeast and during April through May in the North.

**Seed Production and Dissemination-The** fruit is an ovoid, ribbed, 5 to 8 mm (0.2 to 0.3 in) long nutlet. It matures in one season, changing from green to light-greenish-brown or brown on maturity. The nutlet is borne at the base of a distinctive three-lobed involucre, about 2.5 cm (1 in) long; these occur in clusters 5 to 10 cm (2 to 4 in) long. The averages reported for nutlets per kilogram range from 66,000 to 88,000 (30,000 to 40,000/lb), while the range is between 33,000 and 143,000 (15,000 and 65,000/lb) *(48,62).* Large seed crops occur at 3- to 5-year intervals. Seeds are primarily dispersed by birds but are also dispersed short distances by wind. Germination is epigeal. Germination capacity of stratified seed is low-usually less than 60 percent and occasionally as low as 1 to 5 percent-but 100 percent germina-

tion was obtained using immature green seed (54). Dormancy occurs in both the embryo and endosperm (48). Stratification at 4" C (40" F) for 18 weeks, stratification plus gibberellic acid treatment, and scarification of the seed coat plus gibberellic acid treatment all improve germination *(9).*

**Seedling Development-The** types of seedbeds and environments favorable to establishment under natural conditions has to be surmised from nursery experience and the habitat preference of established plants. The optimum nursery seedbed has soils that are rich, loamy, and continuously moist and the site is free of extreme environmental change (48). This approximates natural conditions where the species is most frequently found. Abundant natural reproduction in undisturbed forests indicates the species ability to become established on leaf litter seedbeds under deep shade and with competition from other species *(12,50).* The species also becomes established on sites that are wetter and drier than optimum, as well as on open sites.

American hornbeam responds well to various degrees of overstory removal in regeneration harvests. In two hardwood seed-tree harvest areas in southeastern Arkansas, the proportion of American hornbeam in the reproduction increased during the 18 years after cutting *(30).* Regeneration of the species consisted of advance reproduction, new seedlings, stump sprouts, and root suckers. Sprouts grew from 1.2 to 1.5 m (4 to 5 ft) in the first year. By the 18th year, American hornbeam was becoming subordinate in diameter to sweetgum and the red oaks. The species also responded well to release after clearcutting hemlock-hardwoods in southern New England (34). However, density and basal area stocking of American hornbeam in relation to other species were unaffected after a partial harvest of a pine-hardwood stand in Louisiana (6).

**Vegetative Reproduction-No** information available.

### Sapling and Pole Stages to Maturity

**Growth and Yield-American** hornbeam is unsuited for commercial timber production because it is usually small, twisted, and multi-stemmed. In undisturbed stands, from 70 to 93 percent of the American hornbeam were saplings less than 13 cm (5 in) d.b.h., and less than 1 percent were 25 cm (10 in) d.b.h. or larger (21,401, which is a common minimum diameter for saw logs. Heights of mature individuals generally range from 5 to 6 m (15 to 20 ft) in Canada and from 8 to 11 m (25 to 35 ft) in the South. The

largest individual was found in New York. It has a diameter of 70 cm (27 in), a height of 20 m (65 ft), and a crown spread of 20 m (66 ft) (29).

**Rooting Habit-No** information available.

**Reaction to Competition-American** horn beam is a very shade-tolerant species, capable of persisting in the understories of late seral and climax communities. Tolerance is greatest among seedlings and declines as the trees age, requiring an opening in the canopy for the species to reach maturity. It is one of a few species in both northern and southern forests whose abundant reproduction assures its replacement in stands across a wide spectrum of sites *(27,35)*. This is evidenced by an inverse-J-shaped diameter distribution for the species in many stands. On certain southern sites the species is so aggressive that it will replace overstory species lost through logging or catastrophe and prevent larger species from reproducing *(17,30)*.

Ecologists consider American hornbeam a member of near-climax to climax communities. In Wisconsin where climax species are assigned a climax adaptation number of 10, American hornbeam is rated 7 and 8 on uplands and 8 and 9 on lowlands for the northern and southern parts of the State, respectively *(16)*. Similarly the species is rated 7 in New Jersey *(11)*. It is ranked fifth highest among 79 Central States species on the basis of a multivariate analysis of various species characteristics that favor establishment and growth under climax forest conditions *(58)*.

American hornbeam first appeared in seral communities developing on old fields about 12 to 18 years after the sites were abandoned in North Carolina *(41)* and about 25 to 40 years after the sites were abandoned in New Jersey (26). It enters these communities as a minor component when a sapling-size tree-shrub community is dominant. In much older stands in North Carolina it is more abundant. In maturing second-growth hardwood stands in Connecticut, hornbeam had initially been an important species, the most abundant one, in fact, on moist sites. But, over a 50-year period it declined in density, basal area, and ingrowth, eventually becoming a minor component of all stands (53).

In forests managed for commercial timber production, American hornbeam is considered a weed and is discriminated against in stand improvement. Although hornbeam is considered difficult to kill, herbicides have been effective. Mistblowing a mixture of 2,4-D and 2,4,5-T and injecting 2,4-D, Tordon 101, and Tordon 144 have killed 90 percent or more of the tops *(43,44)*. Prescribed burning is used to control the

understory hardwoods, including American hornbeam, that become established under southern pines.

**Damaging Agents-Insect** and disease damage is not a serious problem with American hornbeam. The species is resistant to frost damage; its succulent foliage can withstand temperatures as low as -8.5" C (17" F) *(1)*. The tree is very windfirm. Recreational use in forested campgrounds disposes it to increased disease infection, insect infestation and decline; it is the tree least capable of withstanding such use of the 22 hardwood species evaluated (47).

American hornbean is susceptible to fire. Wildfires severe enough to kill the hardwood component of white oak stands in Rhode Island eliminated American hornbeam *(10)*. Normally, the species made up 6 percent of the understory stems. However, neither a crown fire nor a ground fire affected the status of American hornbeam in the ninth year after burning a loblolly pine stand in North Carolina *(42)*.

## Special Uses

American hornbeam is an important food of gray squirrels in southern bottom-land hardwoods; otherwise it is of secondary importance to wildlife (25). Seeds, buds, or catkins are eaten by a number of songbirds, ruffed grouse, ring-necked pheasants, bobwhite, turkey, and fox and gray squirrels. Leaves, twigs, and larger stems are consumed by cottontails, beaver, and white-tailed deer *(18,25)*.

Reproduction is browsed by white-tailed deer throughout the species range but it is not a preferred food *(7,28)*. The species is heavily used by beaver because it is readily available in typical beaver habitat (38).

The orange and scarlet coloration in the fall make this an attractive ornamental tree. It is not widely used, however, because it is difficult to transplant and does not do well on exposed sites (60).

The wood of American hornbeam is not important in commerce because the tree is too small, but its tough, dense, and close-grained wood is used for tool handles, levers, wedges, and mallets.

## Genetics

An American hornbeam, variety ***virginiana,*** is recognized by some authorities but its validity is questionable. It replaces the typical form in the northern half of the species range with some overlapping in the Central States. The two forms are separated by features of the bract of the fruiting

ament and the leaves, but in Ohio the two characteristics do not necessarily vary at the same time, resulting in confusion *(8)*.

American hornbeam exhibits clines (from north to south) in several physiological and morphological properties. Fruit weights increase northward (62); the length of cold preconditioning required for bud bursting varies latitudinally *(56)*, and the specific gravity of the wood is higher for trees growing north of latitude 36" N. than for trees growing at latitudes 31" to 36" N. (55).

The species has eight pairs of chromosomes (63).

## Literature Cited

1. Bailey, Robert A. 1960. Summer frosts: a factor in plant range and timber succession. Wisconsin Academy Review of Wisconsin Academy of Sciences, Arts and Letters, Fall 1960:153–156.

2. Bard, G. E. 1946. The mineral nutrient content of the foliage of forest trees on three soil types of varying limestone content. Soil Science Society of America Proceedings 10:419–422.

3. Barnes, Burton V. 1976. Succession in deciduous swamp communities of southeastern Michigan formerly dominated by American elm. Canadian Journal of Botany 54:19–24.

4. Beals, Edward H., and James B. Cope. 1964. Vegetation and soils in an eastern Indiana woods. Ecology 45:777–792.

5. Beschel, R. E., P. J. Webber, and R. Tippett. 1962. Woodland transects of the Frontenac Axis region, Ontario. Ecology 43:386–396.

6. Blair, Robert M., and Louis E. Bnmett. 1976. Phytosociological changes after timber harvest in a southern pine ecosystem. Ecology 57:18–32.

7. Bramble, W. C., and M. K. Goddard. 1953. Seasonal browsing of woody plants by white-tailed deer in the ridge and valley section of central Pennsylvania. Journal of Forestry 51:815–819.

8. Braun, E. Lucy. 1961. The woody plants of Ohio. Ohio State University Press, Columbus. 362 p.

9. Bretzloff, L. V., and N. E. Pellett. 1979. Effect of stratification and gibberellic acid on the germination of *Carpinus caroliniana* Walt. HortScience 14:621–622.

10. Brown, James H., Jr. 1960. The role of fire in altering the species composition of forests in Rhode Island. Ecology 41:310–316.

11. Buell, Murray F., Arthur N. Langford, Donald W. Davidson, and Lewis F. Ohmann. 1966. The upland forest continuum in northern New Jersey. Ecology 47:416–432.

12. Cain, Stanley A. 1935. Studies on virgin hardwood forest: III. Warren's Woods, a beech-maple climax forest in Berrien County, Michigan. Ecology 16:500–513.

13. Caplenor, Donald. 1968. Forest composition on loessial and non-loessial soils in west-central Mississippi. Ecology 49:322–331.

14. Chambless, L. F., and E. S. Nixon. 1975. Woody vegetation-soil relations in a bottomland forest of east Texas. Texas Journal of Science 26:407–416.

15. Colvin, Walter S., and Walter S. Eisenmenger. 1943. Relationships of natural vegetation to the water-holding capacity of soils of New England. Soil Science 55:433–446.

16. Curtis, John T. 1959. The vegetation of Wisconsin. University of Wisconsin Press, Madison. 657 p.

17. Delcourt, Hazel R., and Paul A. Delcourt. 1977. Presettlement magnolia-beech climax of the Gulf Coastal Plain: quantitative evidence from the Appalachicola River bluffs, north-central Florida. Ecology 58:1085–1093.

18. Donohoe, Robert W. 1974. American hornbeam. *In* Shrubs and vines for northeastern wildlife. p. 86-88. John D. Gill, and William M. Healy, comp. USDA Forest Service, General Technical Report NE–9. Northeastern Forest Experiment Station, Upper Darby, PA.

19. Dunn, Christopher P., and Marion T. Jackson. 1978. Phytosociological and ordination analyses of the tree stratum of the beech-maple forest type. *In* Proceedings, Second Central Hardwood Forest Conference. p. 2-21.

20. Egler, F. E. 1940. Berkshire plateau vegetation, Massachusetts. Ecological Monographs 10:145–192.

21. Enterline, David M., and Irwin A. Ungar. 1971. A phytosociological comparison of a thirty-seven year old and a mature hardwood stand. Castanea 36:123–137.

22. Eyre, F. H., ed. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC. 148 p.

23. Golden, Michael S. 1979. Forest vegetation of the lower Alabama Piedmont. Ecology 60:770–782.

24. Hall, T. F., and G. E. Smith. 1955. Effects of flooding on woody plants, West Sandy Dewatering Project, Kentucky Reservoir. Journal of Forestry 53:281–285.

25. Halls, Lowell K., ed. 1977. Southern fruit-producing woody plants used by wildlife. USDA Forest Service, General Technical Report SO-16. Southern Forest Experiment Station, New Orleans, LA. 235 p.

26. Hanks, Jess Paul. 1971. Secondary succession and soils on the inner coastal plain of New Jersey. Bulletin of the Torrey Botanical Club 98:315–321.

27. Harcombe, P. A., and P. L. Marks. 1978. Tree diameter distributions and replacement processes in southeast Texas forests. Forest Science 24:153–166.

28. Harlow, Richard F., Paul A. Shrauder, and Monte E. Seehorn. 1975. Deer browse resources of the Chattahoochee National Forest. USDA Forest Service, Research Paper SE-136. Southeastern Forest Experiment Station, Asheville, NC. 16 p.

29. Hartman, Kay. 1970. American Forestry Association national register of big trees. American Forests 88(4):17–48.

30. Johnson, Robert L. 1970. Renewing hardwood stands on bottomlands and loess. *In* Silviculture and management of southern hardwoods. p. 113-121. Thomas Hansbrough, ed. Louisiana State University Press, Baton Rouge.

31. Johnson, R. L., and R. M. Krinard. 1976. Hardwood regeneration after seed tree cutting. USDA Forest Service, Research Paper SG-123. Southern Forest Experiment Station, New Orleans, LA. 9 p.

32. Kurmis, Vilis, Alvin Fedkenheuer, Myron Grafstrom, and Richard A. Hesse. 1970. Tree reproduction and shrubs in relation to stand and site conditions in St. Croix State Park, Minnesota. Minnesota Forestry Research Notes 217. University of Minnesota School of Forestry, St. Paul. 4 p.

33. Lewin, David C. 1974. The vegetation of the ravines of the southern Finger Lakes, New York region. American Midland Naturalist 91:315–342.

34. Lutz, Harold J. 1928. Trends and silvicultural significance of upland forest successions in southern New England. Yale University School of Forestry, Bulletin 22. New Haven, CT. 68 p.

35. Maycock, Paul F. 1963. The photosociology of the deciduous forests of extreme southern Ontario. Canadian Journal of Botany 41:379–438.

36. Monk, Carl D. 1965. Southern mixed hardwood forest of north-central Florida. Ecological Monographs 35(4):335–354.

37. Monk, Carl D. 1966. An ecological study of hardwood swamps in north-central Florida. Ecology 47:649–654.

38. Nixon, C. M., and J. Ely. 1969. Foods eaten by a beaver colony in southeast Ohio. Ohio Journal of Science 69:313–319.

39. Nixon, Elroy S., and J. A. Raines. 1976. Woody creekside vegetation of Nacogdoches County, Texas. Texas Journal of Science 27:443–452.

40. Nixon, Elroy S., R. Larry Willett, and Paul W. Cox. 1977. Woody vegetation of a virgin forest in an eastern Texas river bottom. Castanea 42:227–236.

41. Oosting, Henry J. 1942. An ecological analysis of the plant communities of Piedmont, North Carolina. The American Midland Naturalist 28:1–126.

42. Oosting, Henry J. 1944. The comparative effect of surface and crown fire on the composition of a loblolly pine community. Ecology 25:61–69.

43. Peevy, Fred A. 1972. Injection treatments for controlling resistant hardwood species. In Proceedings, Twenty-fifth Meeting of the Southern Weed Science Society. p. 252-256.

44. Peevy, Fred A. 1972. Injection treatments for killing bottom-land hardwoods. Weed Science 20:566–568.

45. Putnam, John A., George M. Furnival, and J. S. McKnight. 1960. Management and inventory of southern hardwoods. U.S. Department of Agriculture, Agriculture Handbook 181. Washington, DC. 102 p.

46. Quarterman, Elsie, and Catherine Keever. 1962. Southern mixed hardwood forest: climax in the southeastern Coastal Plain, U.S.A. Ecological Monographs 32:167–185.

47. Ripley, Thomas H. 1962. Tree and shrub response to recreation use. USDA Forest Service, Research Note 171. Southeastern Forest Experiment Station, Asheville, NC. 2 p.

48. Rudolph, Paul O., and Howard Phipps. 1974. *Carpinus* L. Hornbeam. *In* Seeds of woody plants in the United States. p. 266-268. C. S. Schopmeyer, tech. coord. U.S. Department of Agriculture, Agriculture Handbook 450. Washington, DC.

49. Schmalzer, P. A., C. R. Hinkle, and H. R. de Selm. 1978. Discriminant analysis of cove forests of the Cumberland Plateau of Tennessee. *In* Proceedings, Second Central Hardwood Forest Conference. p. 62-86.

50. Skeen, J. N. 1973. A quantitative assessment of forest composition in an east Tennessee mesic slope forest. Castanea 38:322–327.

51. Smalley, Glendon W. 1980. Classification and evaluation of forested sites on the Western Highland Rim and Pennyroyal. USDA Forest Service, General Technical Report SO-30. Southern Forest Experiment Station, New Orleans, LA. 120 p.

52. Smith, H. Clay, and George R. Trimble, Jr. 1970. Mistblowing a hardwood understory in West Virginia with "D-T" herbicide. USDA Forest Service, Research Note NE-115. Northeastern Forest Experiment Station, Upper Darby, PA. 6 p.

53. Stephens, George R., and Paul E. Waggoner. 1980. A half century of natural transitions in mixed hardwood forests. Connecticut Agricultural Experiment Station, Bulletin 783. New Haven. 43 p.

54. Titus, Gerald R. 1940. So-called 2-year seeds germinated first year. American Nurseryman 72(11):22.

55. Wardell, Gordon I. 1976. Autecological and populational investigations of *Carpinus* caroliniana Walt. Thesis (MS.), Western Kentucky University, Bowling Green. 31 p.

56. Wardell, Gordon I., and Joe E. Winstead. 1978. Population differences in bud bursting of *Carpinus caroliniana* Walt. Transactions Kentucky Academy of Science 39:127–130.

57. Wells, Carol, Dennis Whigham, and Helmut Lieth. 1972. Investigation of mineral nutrient cycling in upland Piedmont forest. Journal Elisha Mitchell Scientific Society 8:66–78.

58. Wells, P. V. 1976. A climax index for broadleaf forest: an n-dimensional, ecomorphological model of succession. *In* Proceedings, First Central Hardwood Forest Conference. p. 131-176.

59. Whittaker, R. H. 1956. Vegetation of the Great Smoky Mountains. Ecological Monographs 26:1–80.

60. Wigginton, Brooks E. 1963. Trees and shrubs for the southeast. University of Georgia Press, Athens. 280 p.

61. Wilm, H. G. 1936. The relation of successional development to the silviculture of forest burn communities in southern New York. Ecology 17:283–291.

62. Winstead, Joe E., Burton J. Smith, and Gordon I. Wardell. 1977. Fruit weight clines in populations of ash, ironwood, cherry, dogwood, and maple. Castanea 42:56–60.

63. Woodworth, Robert H. 1931. Polyploidy in Betulaceace. Journal of the Arnold Arboretum 12:206–217.