Populus trichocarpa Torr. & Gray **Black Cottonwood**

Salicaceae Willow family

Dean S. DeBell

Black cottonwood *(Populus trichocarpa)* is the largest of the American poplars and the largest hardwood tree in western North America. Known also as balsam cottonwood, western balsam poplar, and California poplar, it grows primarily on moist sites west of the Rocky Mountains. The most productive sites are the bottom lands of major streams and rivers west of the Cascade Range in the Pacific Northwest. Pure stands may form on alluvial soils. Black cottonwood is harvested and used for lumber, veneer, and fiber products. Many kinds of wildlife use the foliage, twigs, and buds for food, and the tree is planted for shade and in windbreaks and shelterbelts.

Habitat

Native Range

The range of black cottonwood (fig. 1) extends northeast from Kodiak Island along Cook Inlet to latitude 62” 30’ N., then southeast in southeast Alaska and British Columbia to the forested areas of Washington and Oregon, to the mountains in southern California and northern Baja California (lat. 31” N.). It is also found inland, generally on the west side of the Rocky Mountains, in British Columbia, western Alberta, western Montana, and northern Idaho. Scattered small populations have been noted in southeastern Alberta, eastern Montana, western North Dakota, western Wyoming, Utah, and Nevada.

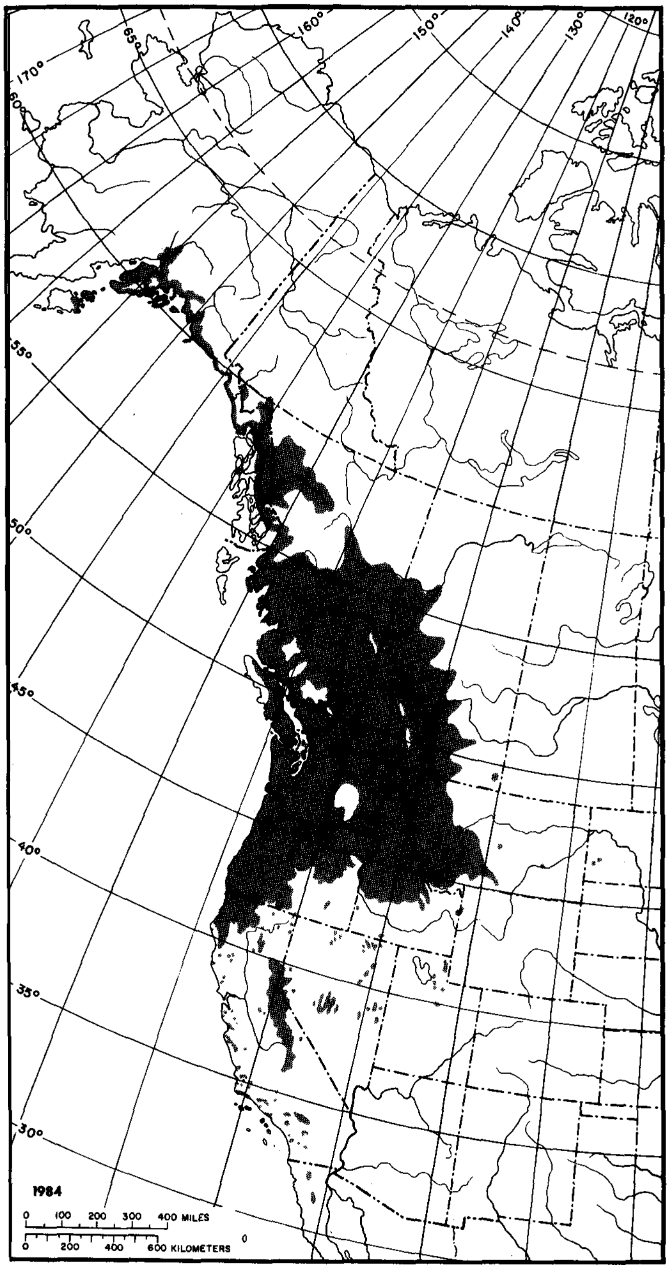

Figure l-The *native range of black cottonwood.*

Climate

Populations of black cottonwood grow in climates varying from relatively arid to humid, but best growth is attained in the humid coastal forests of the Pacific Northwest (23). Annual precipitation ranges from 250 mm (10 in) to more than 3050 mm (120 in). Only about one-third of the annual precipitation occurs during the growing season, and in mountainous and inland areas much of the dormant-season precipitation falls as snow. The frost-free period ranges from about 70 days in the interior areas to more than 260 days in southern California. Maximum temperatures range from 16” to 47” C (60° to 117” F); minimum temperatures, from 0” to -47” C (32” to -53” F).

The author is Principal Silviculturist, Pacific Northwest Research Station, Portland, OR.

Soils and Topography

Black cottonwood grows on a variety of soils and sites, from moist silts, sands, and gravels of islands and new river bars to rich humus soils, loams, and occasionally clay soils of upland sites (23). The most extensive black cottonwood stands are on soils of the order Entisols; the species also is common on Inceptisols and occasionally may be present on soils of other orders. High soil acidity (low pH) may restrict occurrence of black cottonwood on fine-textured soils where other site factors are favorable (9). Studies in British Columbia (27) have indicated that abundant moisture, nutrients, oxygen, and nearly neutral soil reaction (pH 6.0 to 7.0) are required for optimum production. Growth is best at low elevations on deep, moist alluvial soils, but some upland soils are productive cottonwood sites (27). The latter include loessial soils of high nutrient status in areas of abundant rainfall.

Black cottonwood grows from sea level to 600 m (2,000 ft) on the Kenai Peninsula of Alaska and up to 1500 m (5,000 ft) in the Cascade Range of Washington (23). In British Columbia, the elevation range extends to nearly 2100 m (7,000 ft) in the interior valleys of the Selkirk Range. In central and eastern Washington, as well as other dry areas, the species is usually limited to protected valleys and canyon bottoms, along stream banks and edges of ponds and meadows, and to moist toe slopes,

Associated Forest Cover

Black cottonwood often forms extensive stands on alluvial sites at low elevations along the Pacific coast. Arborescent willows are its major associates in two cover types (3): Black Cottonwood-Willow (Society of American Foresters Type 222) and Cottonwood-Willow (Type 235). In the latter type, balsam poplar ***(Populus balsamifera)*** is the dominant cottonwood. Major willow species are Pacific ***(Salix lasiandra),*** northwest ***(S. sessilifolia),*** river (S. *fluviatilis)*, and Scouler ***(S. scouleriana)*** willow *(4).* In other coastal forests, black cottonwood grows in mixture with red alder ***(Alnus rubra),*** Douglas-fir ***(Pseudotsuga menziesii),*** western hemlock ***(Tsuga heterophylla),*** western redcedar ***(Thuja plicata),*** Sitka spruce ***(Picea sitchensis),*** grand fir ***(Abies grandis)***, bigleaf maple ***(Acer macrophyllum),*** Oregon ash ***(Fraxinus latifolia),*** black hawthorn ***(Crataegus douglasii)***, and several birch ***(Betula*** spp.) and cherry ***(Prunus*** spp.) species. Associates in interior forests may include western white pine ***(Pinus monticola)***, ponderosa pine ***(I? ponderosa),*** white fir ***(Abies concolor),*** western larch ***(Larix occidentalis),*** subalpine fir ***(A. lasiocarpa),*** white spruce ***(Picea glauca)***, Engelmann spruce ***(P. engelmannii),*** and quaking aspen ***(Populus tremuloides).***

Shrub species associated with black cottonwood include vine maple ***(Acer circinatum)***, red-osier dogwood ***(Cornus stolonifera)*** and other ***Cornus*** spp., beaked hazel ***(Corylus cornuta),*** Nootka rose ***(Rosa nutkana),*** thimbleberry ***(Rubus parviflorus)***, salmonberry ***(R. spectabilis),*** elder ***(Sambucus*** spp.), bearberry honeysuckle ***(Lonicera involucrata),*** spirea ***(Spiraea*** spp.), and common snowberry ***(Symphoricarpos albus).***

Herbaceous associates include swordfern ***(Polystichum munitum),*** lady fern ***(Athyrium filix-femina)***, horsetail ***(Equisetum*** spp.), stinging nettle ***(Urtica dioica)***, hedge nettle ***(Stachys*** spp.), false solomons-seal ***(Smilacina stellata)***, Canada violet ***(Viola canadensis),*** jewelweed ***(Impatiens*** spp.), enchanters nightshade ***(Circaea alpina)***, golden-saxifrage ***(Chrysosplenium*** spp.), buttercup ***(Ranunculus*** spp.), bittercress ***(Cardamine*** spp.), angelica ***(Angelica*** spp.), loosestrife ***(Lysimachia*** spp.), bedstraw ***(Galium*** spp.), and iris ***(Iris*** spp.).

Presence of some of these understory species provides an indication of site quality in British Columbia (27). Good black cottonwood sites are characterized by salmonberry, nettles, swordfern, and lady fern, as well as vigorous growth of beaked hazel and elder. On medium sites, red-osier dogwood, bearberry honeysuckle, common snowberry, and sometimes thimbleberry and Nootka rose are common. Poor sites are commonly subject to prolonged flooding, and horsetails are dominant.

Life History

Reproduction and Early Growth

Flowering and Fruiting-Black cottonwood is normally dioecious; male and female catkins are borne on separate trees. The species reaches flowering age at about 10 years (25). Flowers may appear in early March to late May in Washington and Oregon, and sometimes as late as mid-June in northern and interior British Columbia, Idaho, and Montana. Staminate catkins contain 30 to 60 stamens, elongate to 2 to 3 cm (0.8 to 1.2 in), and are deciduous. Pistillate catkins at maturity are 8 to 20 cm (3.2 to 8 in) long with rotund-ovate, three carpellate subsessile fruits 5 to 8 mm (0.20 to 0.32 in) long. Each capsule contains many minute seeds with long, white cottony hairs.

Seed Production and Dissemination-The seed ripens and is disseminated by late May to late

June in Oregon and Washington, but frequently not until mid-July in Idaho and Montana (23). Abundant seed crops are usually produced every year. Attached to its cotton, the seed is light and buoyant and can be transported long distances by wind and water. Although highly viable, longevity of black cottonwood seed under natural conditions may be as short as 2 weeks to a month. There is some evidence, however, to suggest a somewhat longer lifespan under apparently adverse conditions. With proper drying and cold storage, viability and capacity to germinate can be maintained for at least 1 year (25).

Seedling Development-Moist seedbeds are essential for high germination *(23)*, and seedling survival depends on continuously favorable conditions during the first month *(25)*. Wet bottom lands of rivers and major streams frequently provide such conditions, particularly where bare soil has been exposed or new soil laid down. Germination is epigeal. Black cottonwood seedlings do not usually become established in abundance after logging unless special measures are taken to prepare the bare, moist seedbeds required for initial establishment (23). Where seedlings become established in great numbers, they thin out naturally by age 5 because the weaker seedlings of this shade-intolerant species are suppressed *(23)*.

Figure *2-Two-year-old sprouts on black cottonwood stumps.*

Vegetative Reproduction-Black cottonwood sprouts readily from stumps (fig. 2), and in one study, satisfactory coppice reproduction was obtained four times in 2-year cutting cycles (8). After logging operations, black cottonwoods sometimes regenerate naturally from rooting of partially buried fragments of branches (9). Sprouting from roots has also been reported (23). The species also has the unusual ability to abscise small shoots complete with green leaves *(6)*. These shoots drop to the ground and may root where they fall or may be dispersed by water transport. In some situations, abscission may be one means of colonizing exposed sandbars.

The species is easily reproduced by rooted and unrooted cuttings *(30)*. The cuttings are made in the dormant season and may be as short as 15 cm (6 in). Most research and small-scale operational plantings have been established with unrooted stem cuttings taken from 1- and 2-year-old wood, 1 to 3 cm (0.4 to 1.2 in) in diameter at the small end and 40 to 60 cm (16 to 24 in) long. Good results have also been obtained with branchwood cuttings, in some instances collected from trees as old as 30 years *(9)*. Usually the cuttings are planted in the spring to a depth of 30 to 40 cm (12 to 16 in). Best establishment and growth are achieved when cuttings have healthy axillary buds, at least one of which remains above ground after planting (22). Plantings of very long cuttings (3 m or 10 ft or more in length) have sometimes been used successfully to overcome problems of weed competition or animal damage (29); in other cases, they have failed, presumably because top growth and thus transpiration stress outstripped root growth and the ability of the root system to provide moisture during the dry summer. The proportion of trees with poor form and the magnitude of crookedness are greater in trees established with long cuttings than with short cuttings *(10)*. Height of trees established from cuttings has frequently exceeded 1.5 m (5 ft) at the end of the first year and 6 m (20 ft) after 4 years *(11)*. Height growth rates of cottonwood sprouts have been even greater.

Sapling and Pole Stages to Maturity

Growth and Yield-Black cottonwood may attain pulpwood size in 10 to 15 years, and saw log-size trees have been observed in plantations less than 25 years old in British Columbia and Washington. For example, dominant and codominant trees of 17 cm (6.7 in) in d.b.h. and 14.8 m (48.5 ft) in height at 9 years have been reported for a good moist site (26). In the lower Fraser River Valley of British Columbia, planted black cottonwoods averaged 20 cm (8 in) in d.b.h. and 16.8 m (55 ft) in height at 10 years, and

Table l-Characteristics of natural stands of black cottonwood by site class (adapted from data collected by the British Columbia Forest Service) and summarized by Smith (30)

Site class and stand age		Average d.b.h.	Stocking	Height[1]	Net volume	Maximum mean annual increment	Age of culmination
	yr	*cm*	*trees/ha*	*m*	*m^3/ha*	*m^3/ha*	*yr*
I,	112	46	294	41.1	302.3	5.5	62
II,	101	33	415	29.6	219.9	2.8	78
III,	87	28	474	21.3	122.8	1.7	96
	yr	*in*	*trees/acre*	*ft*	*ft^3/acre*	*ft^3/acre*	*yr*
I,	112	18	119	135	4,319	79	62
II,	101	13	168	97	3,141	40	78
III,	87	11	192	70	1,755	24	96

[1]Dominants and codominants.

some individual trees were more than 30 cm (12 in) in d.b.h. and 21.3 m (70 ft) in height (29). Growth is considerably less in northerly and interior locations. In the Willamette Valley of Oregon, black cottonwood matures in 60 years or less *(23),* but studies in British Columbia show that the species grows well for as long as 200 years (33). Exceptional trees have attained 180 to 300 cm (72 to 120 in) in d.b.h. and more than 60 m (200 ft) in height (7,351.

Growth and yield data for natural black cottonwood stands are available for the Quesnel region and Skeena River Valley of British Columbia (33). Other Canadian studies have indicated that three site quality classes developed for German poplar *(16)* are satisfactory for black cottonwood stands in British Columbia (30). The Forest Inventory Branch of the British Columbia Forest Service has collected much growth and yield data on natural stands of black cottonwood. Some of this information is summarized in table 1. These data clearly indicate that differences in yield among site classes are large; the mean annual production of site I is nearly twice that of site II, and more than three times that of site III.

Yields from black cottonwood plantations are expected to be much higher than yields from natural stands. Data from three plantations in the lower Fraser River Valley indicate mean annual increments ranging from 10.5 to 15.4 m^3/ha (150 to 220 ft^3/acre) per year (28). A plantation established on a deep alluvial soil in coastal Washington has produced more than 500 m^3/ha (7,242 ft^3/acre) in 24 years (fig. 3) (19). Dominant trees range from 35 to 37 m (115 to 122 ft) in height and 33 to 41 cm (13 to 16 in) in d.b.h.

Rooting Habit-Planted cuttings of black cottonwood root very well; they produce deep and widespread root systems if growth is not restricted by adverse soil conditions. Little information on rooting has been collected in natural or seedling stands.

Reaction to Competition-Black cottonwood is classed as very intolerant of shade. It grows best in full sunlight. On moist lowland sites, it makes rapid initial growth and thereby survives competition from slower growing associated species.

Data from British Columbia indicate that black cottonwood trees can take advantage of wide initial spacing *(1);* diameters of trees and sets established at a 9.14-m (30-R) spacing averaged 30 to 75 percent greater than those of plants established at a 1.82-m (6-R) spacing *(28,29).* Results from a spacing trial in Washington, however, indicate better height and diameter growth at 3.7- by 3.7-m (12- by 12-ft) spacing than at 3.0- by 9.1-m (10- by 30-ft) and 6.1- by 9.1-m (20- by 30-R) spacings *(10).* Black cottonwood responds well to thinning (29).

In the past decade, most of the research on black cottonwood has focused on use of the species in short-rotation, coppice systems for fiber and energy. Spacings have varied from 0.3 by 0.3 m (1 by 1 ft) to 1.8 by 1.8 m (6 by 6 ft) and rotations or cutting cycles of *2* to *8* years *(8,11,12,14).* Mean annual production has ranged from about 2 to more than 16 mg/ha (1

Figure *3-A 24-year-old black cottonwood plantation in coastal Washington with 720 stems per hectare (291 /acre) and mean annual volume increment of about 21.1 m^3/ha (302 ft^3/acre).*

to 7 tons/acre). The most recent findings suggest that rotations longer than 4 years (perhaps 8 or more) result in highest mean annual production *(11)*; with such rotations, spacings of 1.8 by 1.8 m (6 by 6 ft) or wider may be used, provided that competition from grass and weeds is controlled. Higher coppice yield was obtained in a mixed planting of black cottonwood and red alder (a nitrogen-fixing species) than from pure plantings of either species (2). A subsequent study of the black cottonwood-alder mixture on a better site showed no benefits after the second year, presumably because cottonwood shaded and overtopped alder and thus impaired nitrogen fixation *(13)*.

Damaging Agents-Young saplings are frequently injured and sometimes killed by unseasonably early or late frosts (23). Frost cracks also lower quality of wood and provide an entrance for decay fungi *(30)*. Ice storms and heavy snowfall cause considerable breakage and permanent bending (29). Wind damage is common, especially in stands where black cottonwood trees are much taller than surrounding vegetation; top breakage and bending result. Erosion along rivers and major streams also takes its toll in adjacent black cottonwood stands. The species is highly susceptible to fire damage.

Mammals can create serious problems in black cottonwood plantations, especially at time of establishment or soon after. Meadow voles and meadow mice can cause severe losses in young plantations; such damage occurs most commonly on grassy or herb-covered sites. The voles feed on roots and sometimes girdle the lower stem. In some locations, rabbits and hares cause losses in young cottonwoods via clipping and basal girdling damage. Damage also results when beavers use cottonwood for food and construction of dams. Browsing and trampling of saplings by elk and deer sometimes decimate small, isolated plantings. Slugs have girdled cottonwood stems and presumably have eaten buds and newly emergent leaves of recently planted cuttings in the lower Columbia River valley.

Although several insects attack black cottonwood *(5,17)*, none has yet been reported as a pest of economic significance. Foliar feeders include tent caterpillars ***(Malacosoma* spp.)**, two sawflies ***(Phyllocolpa bozemanii*** and ***Nematus currani)***, the satin moth ***(Leucoma salicis)***, and a leaf blotch miner ***(Agromyza albitarsis).*** Oystershell scale ***(Lepidosaphes ulmi)*** was reported as frequently killing twigs and branches, and sometimes a whole tree. A bud midge ***(Contarinia*** spp.) caused considerable injury to buds of stressed trees (e.g., nursery-grown trees that have been transplanted, and trees on dry sites or in dry years) *(9)*. A small bark moth ***(Laspeyresia populana)*** mines the cambium of the trunk and larger branches. Two borers feed under the bark and in the wood, a flatheaded borer ***(Poecilonota montana)*** and the poplar-and-willow borer ***(Cryptorhynchus lapathi).*** The latter is a European insect that is now established throughout much of the range of black cottonwood and has caused some damage in cottonwood plantings. Other flatheaded and roundheaded borers and ambrosia beetles are known to destroy the wood of black cottonwood.

At least 70 fungal species cause decay in cottonwood, but only six fungi cause significant losses in British Columbia; two of these ***(Spongipellis delectans*** and ***Pholiota destruens)*** cause 92 percent of the loss *(15,17,33)*. A leaf rust ***(Melampsora*** spp.) has been observed in young plantations, and susceptibility to the rust appears to vary greatly across the geographic range of the species. This disease limits photosynthesis and causes leaves to fall prematurely, thereby decreasing tree growth and vigor. Severe ***Melampsora*** infections have been observed when clonal material from relatively dry areas (e.g., east of the Cascade Range in Washington or Oregon and northern California) was planted in western Washington *(9)*; in one instance, such infections resulted in death of the clones. Other foliage diseases include leaf-spot syndrome ***(Venturia populina)*** and yellow-leaf blister ***(Taphrina populisalicis).*** A deformity of catkins is caused by ***Taphrina johansonii.*** Cytospora canker ***(Cytospora chrysosperma)*** is widespread under forest conditions but rarely causes significant damage in vigorous cottonwood stands. It may cause problems, however, to cuttings in nurseries and plantations. Stem cankers in various areas have been reported as caused by ***Dothichiza populea, Fusarium*** spp., ***Hypoxylon mammatum, Nectria galligena,*** and ***Septoria musiva.*** None appear to be of great significance in management of black cottonwood, but severe attacks of a bacterial canker have reportedly limited planting of the species in Europe. Black cottonwood is also subject to the condition known as wet wood, which leads to wood collapse during drying.

Special Uses

Black cottonwood has been planted as windbreaks and shelterbelts in conjunction with irrigated agriculture in the Columbia River basin.

The wood of black cottonwood is similar to that of other cottonwoods *(20,34)*. It has light color, straight grain, fine, even texture, and is light in weight. It dries easily, is moderately stable in use, and, although not strong, is tough for its weight.

Black cottonwood has short, line fibers and is used to produce pulp for high-grade book and magazine papers. The species peels easily, and its veneer is used as core and cross-banding stock in plywood and in baskets and crates. The light weight, good nailing characteristics, and light color of the lumber are ideal for manufacture of pallets, boxes, and crates. The lumber is also used in concealed parts of furniture. Fiberboard and flakeboard are made from black cottonwood. In early days, it was used for cooperage.

Genetics

Population Differences

Black cottonwood exhibits considerable variation throughout its range. Photoperiodic studies conducted under uniform environmental conditions in Massachusetts have shown that northern provenances cease growth earlier than southern provenances *(21).* Moreover, cessation of growth among clones from the same latitude was related to length of the growing season (frost-free days) at places of origin (that is, elevation). Another study *(18)* conducted with clones indicates that several aspects of shoot growth are under genetic control: date of flushing, amount of early growth, growth rate in midseason, date of cessation, and average length of internode. A more recent study (36) demonstrated a large range of variation in leaf, branch, and phenology characters in 50 clones (five each from 10 natural populations growing in drainages west of the Cascade Range). Population means for several characters varied clinally with source latitude, longitude, and/or elevation. In general, southwestern clones developed smaller leaves, had more numerous and more erect branches, and continued growth later in the fall than northeastern clones. Experiments in pots and flats have shown that some clones of black cottonwood grow taller in the presence of another clone than when planted by themselves (32).

Hybrids

Black cottonwood hybridizes freely with balsam poplar *(Populus balsamifera)* where the ranges of the two species overlap (35). Another natural hybrid, the Parry cottonwood, resulting from crosses with *P. fremontii* is native to California. A hybrid *(Populus x generosa* Henry) between *P. angulata* (now considered either a variety or cultivar of *l? deltoides)* and *P. trichocarpa* was developed in England (24). *Also, P. maximowiczii x trichocarpa* and *P. deltoides x P. trichocarpa* hybrids have been planted in the northeastern United States. Recent work in which *P. trichocarpa* was crossed with superior selections of *P. deltoides* from the southern United States has produced hybrids of markedly superior growth performance *(12,31).*

Literature Cited

1. Armson, K. A., and J. H. G. Smith. 1978. Management of hybrid poplar. Case study 5, in forest management in Canada. Canadian Forestry Service FMR-X-103. Ottawa, ON. 27 p.
2. DeBell, D. S., and M. A. Radwan. 1979. Growth and nitrogen relations of coppiced black cottonwood and red alder in pure and mixed plantings. Botanical Gazette 140 (Supplement): S97–S101.
3. Eyre, F. H., ed. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC. 148 p.
4. Franklin, Jerry F., and C. T. Dyrness. 1973. Natural vegetation of Oregon and Washington. USDA Forest Service, General Technical Report PNW-8. Pacific Northwest Forest and Range Experiment Station, Portland, OR. 417 p.
5. Furniss, R. L., and V. M. Carolin. 1977. Western forest insects. U.S. Department of Agriculture, Miscellaneous Publication 1339. Washington, DC. 654 p.
6. Galloway, G., and J. Worrall. 1979. Cladoptosis: a reproductive strategy in black cottonwood? Canadian Journal of Forest Research 9(1):122–125.
7. Harlow, William M., and Ellwood S. Harrar. 1950. Textbook of dendrology. McGraw-Hill, New York. 555 p.
8. Harrington, Constance A., and Dean S. DeBell. 1984. Effects of irrigation, pulp mill sludge, and repeated coppicing on growth and yield of black cottonwood and red alder. Canadian Journal of Forest Research 14(6):844–849.
9. Heilman, Paul. 1981. Personal communication. Western Washington Research and Extension Center, Washington State University, Puyallup.
10. Heilman, Paul E., and Gordon Ekuan. 1979. Effect of planting stock length and spacing on growth of black cottonwood. Forest Science 25(3):439–443.
11. Heilman, Paul, and D. V. Peabody, Jr. 1981. Effect of harvest cycle and spacing on productivity of black cottonwood in intensive culture. Canadian Journal of Forest Research 11(1):118–123.
12. Heilman, Paul E., and R. F. Stettler. 1985a. Genetic variation and productivity of *Populus trichocarpa* and its hybrids. II. Biomass production in a 4-year-old plantation. Canadian Journal of Forest Research 15(2):384–388.
13. Heilman, Paul, and R. F. Stettler. 1985b. Mixed, short-rotation culture of red alder and black cottonwood: growth, coppicing, nitrogen fixation, and allelopathy. Forest Science 31(3):607–616.
14. Heilman, P. E., D. V. Peabody, Jr., D. S. DeBell, and R. F. Strand. 1972. A test of close-spaced, short-rotation culture of black cottonwood. Canadian Journal of Forest Research 2(4):456–459.

15. 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.

16. Hesmer, H. 1951. Das Pappelbuch. Verlag des Deutschen Pappelvereins, Bonn. 304 p.

17. Maini, J. S., and J. H. Cayford, eds. 1968. Growth and utilization of poplars in Canada. Canadian Department of Forestry and Rural Development, Forestry Branch, Department Publication 1205. Ottawa, ON. 257 p.

18. Mohn, Carl Ames. 1969. A study of the genetic control of shoot growth patterns in *Populus trichocarpa.* (Abstract.) Dissertation Abstracts 69:16430.

19. Murray, Marshall D., and Constance A. Harrington. 1983. Growth and yield of a 24-year-old black cottonwood plantation in western Washington. Tree Planters' Notes 34(2):3–5.

20. Panshin, A. J., and Carl de Zeeuw. 1970. Textbook of wood technology. vol. 1. McGraw-Hill, New York. 705 p.

21. Pauley, Scott S., and Thomas 0. Perry. 1954. Ecotypic variation in the photoperiodic response in poplars. Journal of the Arnold Arboretum 35:167–188.

22. Radwan, M. A., J. M. Kraft, and D. S. DeBell. 1987. Bud characteristics of unrooted stem cuttings affect establishment success of cottonwood. USDA Forest Service, Research Note PNW-461. Pacific Northwest Research Station, Portland, OR. 8 p.

23. Roe, Arthur L. 1958. Silvics of black cottonwood. USDA Forest Service, Miscellaneous Publication 17. Intermountain Forest and Range Experiment Station, Ogden, UT. 18 p.

24. Schreiner, Ernst J. 1959. Production of poplar timber in Europe and its significance and application in the United States. U.S. Department of Agriculture, Agriculture Handbook 150. Washington, DC. 124 p.

25. Schreiner, Ernst J. 1974. ***Populus*** L. Poplar. *In* Seeds of woody plants in the United States. p. 645-655. C. S. Schopmeyer, tech. coord. U.S. Department of Agriculture, Agriculture Handbook 450. Washington, DC.

26. Silen, Roy R. 1947. Comparative growth of hybrid poplars and native northern black cottonwoods. USDA Forest Service, Research Note 35. Pacific Northwest Forest and Range Experiment Station, Portland, OR. 3 p.

27. Smith, J. H. G. 1957. Some factors indicative of site quality for black cottonwood ***(Populus trichocarpa*** Torr. and Gray). Journal of Forestry 55 (8):578–580.

28. Smith, J. Harry G. 1980. Growth and yield of poplar in British Columbia. Paper presented at 1980 meeting of the Poplar Council of Canada; on file at University of British Columbia, Faculty of Forestry, Vancouver, BC. 11 p.

29. Smith, J. H. G., and G. Blom. 1966. Decade of intensive cultivation of poplars in British Columbia shows need for long-term research to reduce risks. Forestry Chronicle 42(4):359–376.

30. Smith, J. H. G., P. C. Haddock, and W. V. Hancock. 1956. Topophysis and other influences on growth of cuttings from black cottonwood and Carolina poplar. Journal of Forestry 54(7):471–472.

31. Stettler, Reinhard F., Ruth C. Fenn, Paul E. Heilman, and Brian J. Stanton. 1988. ***Populus trichocarpa x Populus*** *deltoides* hybrids for short rotation culture: variation patterns and 4-year field performance. Canadian Journal of Forest Research 18(6):745–753.

32. Tauer, C. G. 1975. Competition between selected black cottonwood genotypes. Silvae Genetica 24(2/3):44–49.

33. Thomas, G. P., and D. B. Podmore. 1953. Studies in forestry pathology. XI. Decay in black cottonwood in the middle Fraser region, British Columbia. Canadian Journal of Botany 31:672–692.

34. U.S. Department of Agriculture, Forest Service. 1974. Wood handbook: Wood as an engineering material. U.S. Department of Agriculture, Agriculture Handbook 72. Rev. Washington, DC. 433 p.

35. Viereck, Leslie A., and Elbert L. Little, Jr. 1972. Alaska trees and shrubs. U.S. Department of Agriculture, Agriculture Handbook 410. Washington, DC. 265 p.

36. Weber, J. C., R. F. Stettler, and P. E. Heilman. 1985. Genetic variation and productivity of ***Populus trichocarpa*** and its hybrids. I. Morphology and phenology of 50 native clones. Canadian Journal of Forest Research 15(2):376–383.