Populus balsamifera L. Balsam Poplar

Salicaceae Willow family

John C. Zasada and Howard M. Phipps

Balsam poplar *(Populus balsamifera)* is the northernmost American hardwood. It grows transcontinentally on upland and flood plain sites but attains the best development on flood plains. It is a hardy, fast-growing tree which is generally short lived, with some trees reaching 200 years. Other names are balm-of-gilead, barn, tacamahac, cottonwood, or heartleaf balsam poplar. Many kinds of animals use the twigs for food. The light, soft wood is used for pulp and construction.

Habitat

Native Range

The range of balsam poplar (fig. 1) spans about 110" in longitude (55" to 165" W.) and 26" in latitude (42" to 68" N.). It extends across North America along the northern limit of trees from Newfoundland, Labrador, and Quebec west to Hudson Bay and northwest to Mackenzie Bay From northwest Alaska, its range extends south to southwest Alaska and part of southcentral Alaska, north and east British Columbia; east to southeast Saskatchewan, east North Dakota, northeast South Dakota, Minnesota, Wisconsin, northwest Indiana, Michigan, southern Ontario, New York, and Maine. It is local in the western mountains, south to northeast Oregon, Idaho, extreme northern Utah, central Colorado, extreme northwest Nebraska, and the Black Hills of South Dakota and Wyoming. It is also scattered in northern Iowa, northeast Ohio, Pennsylvania, northern West Virginia, extreme eastern Maryland, and northwestern Connecticut.

Climate

Most of the range of balsam poplar has a continental climate, but some is in the maritime zone and the transition between these two broad regions. Average temperature ranges from -30" to -4" C (- 22" to 25" F) in January and from 12" to 24" C (53" to 75" F) in July. The lowest temperatures range from -18" to -62" C (–10° to -79" F); the highest from 30" to 44" C (85" to 110° F). Annual precipitation is lowest in central Alaska (15 to 30 cm; 6 to 12 in) in the Yukon–Tanana drainage. The highest precipitation, 140 cm (55 in), occurs in the Maritime Provinces of eastern Canada. Distribution of precipitation varies throughout the range, but prolonged summer droughts are uncommon. Annual snowfall is lowest in interior Alaska (100 to 200 cm; 40 to 80 in) and highest in Newfoundland (400 cm; 160 in). Maximum summer daylength varies from 16 to 24 hours. Minimum daylength in winter drops to zero above the Arctic Circle. The frost-free period varies from 75 to 160 days, The longest growing seasons are in the southern part of the range and the shortest in the north, but growing seasons can be 120 days in parts of Alaska.

Soils and Topography

Maximum development of balsam poplar stands occurs on the river flood plains in Alaska, Yukon Territory and Northwest Territories, British Columbia, and Alberta. Balsam poplar can become established shortly after formation of a sand or gravel bar. At 15 to 25 years after site formation, it assumes dominance and retains it for 50 to 75 years, disappearing 100 to 200 years after site formation *(40,51)*. During stand development, depth of medium to fine sand and silt-textured material accumulates from a few centimeters to as much as 2 to 3 m (6.6 to 9.8 ft). Periodic flooding occurs at spring breakup and in later summer-sometimes both; duration and degree of flooding depend on terrace height and distance from the river *(40)*. The soil that develops consists of river sediment and organic matter in alternating layers of variable thickness. In northeast British Columbia, average annual rate of sediment accumulation was estimated to be 6 to 10 cm (2.4 to 3.9 in) from site age 0 to 50; beyond age 50, accumulation was estimated at 8 mm (0.3 in) *(40)*. Balsam poplar grows primarily on soils of the order Inceptisols and, to a lesser extent, of the order Entisols.

Before balsam poplar becomes dominant on a site, the river is the predominant influence on soil development. As balsam poplar becomes dominant, the vegetation becomes of equal importance in soil development *(50,51)*. This results from the continuous aerial plant cover and increased litter (leaf) fall and decreased rate of siltation. In the balsam poplar stage, (a) forest floor nitrogen content increases while soil nitrogen remains relatively constant; (b) soil carbon and cation exchange capacity

The authors are Silviculturist, Pacific Northwest Research Station, Portland, OR, and Research Forester (retired), North Central Forest Experiment Station, St. Paul, MN.

Figure ***l-The native range of balsam poplar.***

Figure 2—*Mature balsam poplar stand growing at the confluence of the Chulitna and Susitna Rivers in south-central Alaska.*

increase; (c) sulfate concentration, the major component of a salt crust common in early stages of succession, declines; and (d) depth and importance of the forest floor increases (51).

Soil temperatures in balsam poplar stands are cooler than in earlier stages of succession but warmer than the white spruce stands that succeed them. Soils are usually thawed to a depth of 1.5 m (4.9 ft) or more by May. Soil temperatures during the growing season vary from 8” to 14” C (46” to 57” F) (53). Permafrost has been reported on only the most northern sites; for example, permafrost is found at a depth of about 1 m (3.3 ft) during the growing season along the delta of the Mackenzie River, where summer soil temperatures in the surface 0.5 m (1.6 ft) range from 2” to 10” C (36” to 50” F) during the growing season ***(18).*** On Alaska flood plain sites, soil pH was 6.9 to 8.2; nitrogen, 0.6 to 0.01 percent; phosphorus, 7.0 to 0.3 parts per million; and cation exchange capacity, 13.1 to 5.6 me/100 g (66).

The roots of balsam poplar in young stands can extract water from near the water table and the capillary zone above it. As stands age, the importance of water supplied by rain and snow increases.

In the eastern portion of the range and on upland sites in the west portion, balsam poplar occurs on soils developed from lacustrian deposits, glacial till, outwash, and loess. In Saskatchewan, it is frequently associated with aspen on moderately well-drained sites, but its distribution is usually restricted to local depressions or drainage channels *(10,31).* A higher proportion of balsam poplar relative to aspen in the white spruce-feathermoss ecosystem indicates sites that have excess water in early spring ***(31).*** It was the only one of seven boreal tree species that was associated with clay soils and was found on poorly drained sites having a pH greater than 7.2 *(10).* Balsam poplar grows in “hotter” ecoclimates and “fresh” to “wetter” soils in the moderate, humid site regions of eastern and central Ontario. In moist, subhumid western Ontario, it most commonly occurs on fresh to wetter soils in the areas of “normal” ecoclimate. In Ontario, balsam poplar occurs on sites that are relatively rich in nutrients and less acidic *(19).* In the open, subarctic woodlands in northern Ontario, balsam poplar and white spruce form the only closed forests, and these grow in river bottoms (5). Balsam poplar grows on dry, sandy, southfacing sites near treeline in Canada.

The northernmost balsam poplar stands are associated with warm springs that arise in the northern foothills of the Brooks Range in Alaska. This area is in the zone of continuous permafrost, and these stands are forested islands in a sea of arctic tundra.

Associated Forest Cover

Balsam poplar occurs in the following forest cover types ***(13):*** Balsam Poplar (Society of American Foresters Type 203), White Spruce-Aspen (Type 251), White Spruce (Types 107 and 201), Jack Pine (Type 1), Aspen (Type 16), Red Spruce-Balsam Fir (Type 33), Northern White-Cedar (Type 37), Black Ash-American Elm-Red Maple (Type 39).

In eastern North America, balsam poplar is found mainly in mixed stands where other species dominate. In Saskatchewan, it is a component of the following forest types: Aspen-hazelnut *(Populus tremuloides / Corylus cornuta)*, white spruce ***(Picea glauca)***-feathermoss, aspen-sarsaparilla *(Aralia nudicaulis)*/twinflower ***(Linnaea borealis),*** white spruce/aspen-bunchberry (Cornus canadensis)/bishops cap *(Mitella **nuda**),* black spruce ***(Picea mariana)***-feathermoss, and white spruce-horsetail (*Equisetum* spp.) ***(31).*** Balsam poplar is uncommon in boreal white spruce forests east of about 75” longitude and is not present in black spruce stands east of 85 to 86” longitude. It grows with white spruce east of 75” longitude, however (45). Other associated trees are balsam fir ***(Abies balsamea)***, paper birch ***(Betula papyrifera),*** black ash ***(Fraxinus nigra),*** American elm *(Ulmus **americana**),* red maple *(Acer rubrum)*, tamarack *(**Larix** laricina)*, and northern white-cedar *(Thuja canadensis).*

In western and northern parts of the range, balsam poplar is associated with balsam/alpine fir *(Abies **lasiocarpa**),* aspen, paper birch, white spruce, and black spruce on upland sites. It reaches its most widespread development on the river flood plains. On these sites, it occurs in pure stands and is associated with mountain alder *(Alnus incana)* and various willows *(e.g., Salix alaxensis,* S. *interior)* during early stand development and white spruce in later stages when it finally disappears from these sites *(53,57).*

Low shrubs associated with balsam poplar include red-osier dogwood *(Cornus stolonifera)*, bunchberry, mountain maple *(Acer spicatum)*, bearberry honeysuckle *(Lonicera involucrata)*, beaked hazel, American cranberry bush *(Viburnum trilobum)*, highbush cranberry *(V. edule)*, red raspberry *(Rubus idaeus* var. *canadensis* and *strigosus)*, prickly rose *(Rosa acicularis)*, mountain cranberry *(Vaccinium vitis-idaea)*, devil's club *(Oplopanax horridum)*, and red currant *(Ribes triste).*

Some associated herbaceous plants are horsetails *(Equisetum arvense, E. pratense)*, bluejoint reedgrass *(Calamagrostis canadensis)*, bedstraws *(Galium boreale, G. triflorum)*, fireweed *(Epilobium angustifolium)*, panicle bluebells *(Mertensia paniculata)*, red baneberry *(Actaea rubra)*, alpine pyrola *(Pyrola asarifolia)*, claspleaf twistedstalk *(Streptopus amplexifolius)*, wild sarsaparilla, butterbur *(Petasites* spp.), and bishops cap.

In mixed stands, various feathermosses (e.g., *Hylocomium splendens, Pleurozium schreberi*) and lichens may be associated with balsam poplar. In Alaska, two mosses, *Eurhynchium pulchellum* and *Mnium cuspidatum*, have been reported in flood plain stands (53). Moss and lichen cover is generally low in these stands.

Life History

Reproduction and Early Growth

Flowering and Fruiting-Balsam poplar generally reaches flowering age between 8 and 10 years. It produces large seed crops almost every year, but significant annual variation in production can occur by individual stands and trees *(47,59).* Flowering in this dioecious species occurs before leaf flush, in April and May throughout most of the range, but not until June or July at northern limits and upper elevations.

The regional ratio of male to female clones was found to be 1:1 on treeline sites in northern Quebec. Female clones occurred on sites with a relatively milder climate or those that were more fertile and mesic; male clones were more common on inland sites with drier soil conditions. Most stands were made up of more than one clone; however, monoclonal stands usually contained a male clone, and polyclonal stands usually had only female clones. Stand density and area were greater in male than in female clones *(6).*

Flower clusters (catkins) are 5 to 9 cm (2 to 3.5 in) with many small flowers about 3 mm (0.12 in) long. Male flowers have 20 to 30 reddish stamens. Mature female catkins are 10 to 15 cm (4 to 6 in) long. Capsules are a lustrous green during development but turn dull green at time of dispersal. Male flowers are shed promptly and decay; female catkins are shed shortly after dispersal is completed but remain identifiable for the remainder of the summer *(2,56).*

Seed Production and Dissemination-Seeds are tan and small (0.3 mg or 0.005 gr); they do not have an endosperm at maturity. Dispersal begins in May and June throughout most of the range, but dissemination can occur through the last week of July in northernmost stands *(33,59).* Dispersal of seeds lasts for at least 2 weeks. Viable seeds are found on trees 4 to 6 weeks after the start of dispersal in some years. Relatively warm, dry weather causes rapid dispersal. Each small seed is attached to a tuft of long, silky hair ideally suited for long distance dispersal by the wind. Under warm, dry conditions, seeds are frequently carried upward by convection currents. Large quantities of seeds fall within the stand, however, and large numbers of short-lived germinants can be found on suitable substrates in mature stands (59). On flood plain sites, large quantities of seeds land in water and may be carried long distances by rivers. Seeds sink rapidly, however, when detached from the silky hairs.

Although most balsam poplar seeds die within several weeks of dispersal, some remain viable for 4 to 5 weeks. Duration of viability is dependent on temperature and moisture; cooler, drier conditions prolong viability. Viability can be maintained at 90 percent or greater for at least 3 years when seed is stored in airtight containers at -10" C (14° F) *(4,63,65).*

Seedling Development-The seed does not exhibit dormancy, and germination occurs over a wide range of temperatures (5" to 35" C; 41" to 95" F) provided moisture is adequate (63). Germination can occur under water, and even mild water deficits reduce germination (33). Germination is reduced by exposure to the concentrations of salt that commonly occur as crusts on river flood plains (33). In a comparison of germination on different types of naturally occurring substrates, balsam poplar germinated over a wider range of substrate moisture content on sand-algal crusts than on silt, sand, or silt-salt crust substrates (33). Complete germination occurs in the dark and over a range of overstory conditions (59). Burial of seed up to several millimeters does not prevent germination but reduces it.

Germination is epigeal and can occur after the seed has separated from the silky hair or in association with the hairs. Under ideal conditions, germination is rapid, and cotyledons can be expanded in 18 to 24 hours (33,641. The rate of germination declines below 15" to 20" C (59" to 68" F) (64). A conspicuous ring of fine hairs is formed at the root-hypocotyl junction. These hairs anchor the seedling to the substrate until the radicle provides a more substantial foothold. Moist mineral soil surfaces are the best seedbeds. Seeds germinate on moist organic seedbeds, but seedling survival is poor, and most seedlings die soon after germination *(6,59,67)*.

Seedling development depends on photosynthesis soon after germination. After the first growing season, hypocotyl length varies from 2 to 5 mm (0.08 to 0.20 in) under Alaska conditions. Tricotyledonous seedlings do occur, but they are rare. Albinism can be as high as 5 'percent in some seed lots in Alaska. Leaf production begins with the development of two leaves separated by 0 to 4 mm (0 to 0.16 in); the first leaf is 1 to 3 mm (0.04 to 0.12 in) above the cotyledons. Subsequent leaf production and internode development vary by microsite and with seedling density, with maximum production of 11 leaves under field conditions in Alaska. The third and fourth internodes are the longest (25).

The height and dry weight of first-year seedlings are affected by density *(25,39)*. Seedlings grown in a greenhouse from an Ontario seed source ranged from 5 to 32 cm (2 to 12.5 in) in height and 11 to 220 mg (0.17 to 3.4 gr) per plant as density decreased from about 59,000 to 323 seedlings/m^2 (39). Seedlings grown under normal environmental conditions in interior Alaska ranged from 2 to 6 cm (0.8 to 2.4 in) tall at sowing densities ranging from 73,400 to 1 seeds/m^2 (6,820 to 0.1/ft^2). First-year shoot growth was proleptic with no branch formation unless the apex was damaged. Dry weight of leaves and stems ranged from 20 to 520 mg (0.3 to 8.0 gr) (25). Average root length varied from 9 to 13 cm (3.5 to 5.1 in).

On flood plain sites, height growth of planted seedlings in early successional stages was twice that in later stages. Growth appeared to be controlled by nitrogen availability in some stages of succession and a combination of light, water, and nutrient availability in other stages. In greenhouse studies, balsam poplar seedling biomass was greater on soils from alder stands than on those from earlier successional stages, suggesting that poplar benefits from nitrogen fixation. The growth of seedlings on early successional soils increased significantly when they were fertilized, but growth on alder soils was not affected by fertilization (58). Natural seedlings were found only in the early successional stages, and growth rate was similar in each of these stages.

Vegetative Reproduction-Balsam poplar is one of the most versatile members of the Salicaceae in its potential for vegetative reproduction. New stems originating from intact or broken roots, preformed or adventitious buds on stumps or at the base of trees, and buried stems or branches have been observed in primary or secondary succession on flood plain and upland sites *(33,66,69)*.

In Alaska, segments of stems and branches broken and buried during autumn logging contribute to regeneration, This buried material was from 2 to 6 cm (0.8 to 2.4 in) in diameter and 10 to 200 cm (4 to 79 in) long (69).

Dormant hardwood stem cuttings, as old as 10 to 15 years and probably older, will produce roots and new shoots. Older cuttings frequently take longer to root than younger cuttings. The distal portion of the current year's growth may root more poorly than the basal part of the current growth and 2-year-old wood. In a rooting study conducted with material from Ontario, cuttings collected after December had a higher percentage of rooting, more roots per cutting, and a higher percentage of cuttings with bud activity than those collected before December. Age of the parent tree had no effect on number of roots produced or bud activity (8). Clonal differences are a major source of variation in rooting percentage and the number of primary roots produced by dormant cuttings *(15)*. Rooting potential for hardwood cuttings ranges from 75 to 100 percent *(8,24)*; rooting of softwood cuttings ranges from 23 to 63 percent, depending on treatment (24).

Unrooted stem sections have been used with varying success in regeneration of field sites. In one study in Alaska, survival after 3 years ranged from 15 to 82 percent. Highest survival was observed on gravel substrates, least on silt and sand soils. Third-year height was greatest on silt and sand-l.2 m (3.9 ft) (28). In a prescribed burn, survival after 5 years was generally low; microsites burned to mineral soil supported the best growth. Relatively deep organic layers, whether burned or unburned, provide a poor environment for the establishment of unrooted stem cuttings *(65,66)*.

Stem cuttings (hardwood and softwood or greenwood cuttings) have been the major means of stand establishment for the short-rotation intensive culture of balsam poplar and hybrid poplars in Wisconsin, Ontario, and other areas *(20)*. Hardwood cuttings are grown in clonal orchards, harvested, stored, and planted either rooted or unrooted. Clones that are difficult to root may survive better if they are regenerated from rooted cuttings. Greenwood cuttings provide a means of rapidly increasing the number of desirable clones, but they must be rooted before planting *(20)*.

In the greenhouse, root cuttings of balsam poplar clones from Utah produced surface suckers from suppressed buds and end suckers from the cambium at the cut end (46). Root cuttings also produce new lateral roots from the same origins as suckers. Alaskan clones respond similarly *(69)*.

Production of suckers after disturbance of the parent tree varies; the response is generally less than that of aspen which suckers prolifically. In Alaska, stocking after 3 years ranged from 4 to 61 percent; densities were 1 to 2 plants/m^2 (3 to 8/milacre) in harvested balsam poplar stands. Suckers made up about 80 percent of the stocking in the summer- and winter-logged areas but only 27 percent in a fall-harvested area. Production was on intact and broken roots within the upper 2 cm (0.8 in) of the surface soil. Average diameter of roots producing suckers was 1 cm (0.4 in) *(69)*. In a 40- to 50-year-old stand on the Tanana River in interior Alaska, stocking was 83 percent and density 2 trees/m^2 (8/milacre) (25). In Saskatchewan, sucker regeneration was observed on dry, moist, and wet regimes. Stocking was 12 percent in the aspen-hazelnut type; 5 percent in the white spruce-aspen-bunchberry type; 5 percent in the white spruce/feathermoss type; and 7 percent in the aspen/sarsaparilla/twinflower type *(31)*.

Density of suckers is greatest on sites where the organic layers are disturbed. Organic layers are effective insulators and may limit sprouting by controlling soil temperature, particularly in high latitude forests (69).

Production of suckers may be important in the invasion and establishment of balsam poplar on disturbed sites and in primary succession. Expansion has been observed on flood plains from established stands to areas that did not have poplar *(40)*. Colonization by clonal expansion is believed to be more important on dry sites where the probability of seedling establishment is low (33). The area covered by individual clones on productive forest sites is not well documented; one 15-year-old clone consisted of 27 ramets and covered an area of 350 m^2 (3,700 ft^2) *(33)*.

The extent of clonal development is best documented at elevational and latitudinal treeline sites where seedling establishment is limited and development of stands through vegetative growth is the main means of colonization and maintenance of the species *(6,35)*. Scattered groves of balsam poplar in the Brooks and Alaska Ranges of Alaska were found to be individual clones. Representative clones covered from 100 to 200 m^2 (1,060 to 2,110 ft^2) and contained from 90 to 150 ramets. Clones with the oldest ramets (114 years old) were found on the Brooks Range sites. Ramets did not occur in areas with dense shrub cover (35).

New shoots also form on stumps from suppressed buds and adventitious buds developed from undifferentiated inner bark. Most originate in the inner bark at the top of the stump. Sprouting response varies with genotype and declines as tree age increases. It may be high (50 to 100/stump) initially, but production and survival of sprouts vary with season and logging method. The percentage of stumps with sprouts declines over a 2- to 5-year period (69).

Balsam poplar stump sprouts may be of little potential value in replacement of trees in mature stands after disturbance because of the fragile connection between sprout and stump. In intensively cultured stands grown on short rotations, coppicing is used to replace the new crop after harvest of the original stand established from stem cuttings. Individual cuttings may produce 10 to 20 sprouts 1 year after harvesting; 4 to 8 sprouts will survive after 2 years (20).

The growth potential of balsam poplar vegetative reproduction is greater than that of early seedling growth. Average height of balsam poplar was about 1 m (3.2 ft) after 3 years; height of dominants was 2.5 to 3.0 m (8.1 to 9.8 ft). The age of suckers at breast height (1.5 m or 4.9 ft) varies with site quality and the degree and type of disturbance *(21,25)*.

The most detailed data available for growth of vegetative reproduction comes from stands of a l? *balsamifera x tristis* hybrid established from stem cuttings. After harvest of the original stands, coppice stands are managed for several rotations. Mean annual increment (stem plus branchwood) is 21 to 25 t/ha (9.5 to 11.0 tons/acre), depending on stand age and rotation length *(11)*. Other studies with this hybrid have shown that 1- and 2-year-old coppice stands are taller and more productive than stands of similar age established from stem cuttings. Architecturally, the stands are different in that each individual in coppice stands has 10 to 20 stems at age 1 and 4 to 8 stems at age 2. Stands from stem cuttings usually contain one stem per individual at this age (20).

Internode length on young vegetative regeneration is usually greatest in the lower part of the annual shoot. Buds are longest in the central part of the shoot, and the terminal bud is equal to the largest nodal bud. First-order branches are smallest at the base of the previous year's growth and longest near the top. Angle of divergence of first-order branches is 30" to 40" (37).

Sapling and Pole Stages to Maturity

Growth and Yield-Large balsam poplar throughout much of the range may be 90 to 180 cm (35 to 71 in) in diameter and 23 to 30 m (75 to 100 ft) in height (44). In the northern part of the range, this species is frequently the largest tree in 80- to loo-year-old stands. Beyond this age, conifers, which eventually replace balsam poplar, usually attain greater heights but not necessarily larger diameters (fig. 3).

The form or branching pattern of young trees is excurrent, with a clearly defined main bole and conical crown. In the 80- to 100-year-old age class, trees tend to have a more rounded crown, however, and the central stem gives rise to a more deliquescent or decurrent growth habit. On good sites the excurrent growth habit is present to at least 40 to 50 years. On poorer sites, the decurrent growth habit may occur earlier. The branching system is composed of long and short shoots; short shoots produce most of the leaves. Long shoots account for height growth and lateral branch extension.

Balsam poplar vegetative buds exhibit unconditional dormancy in the fall and early winter. A brief chilling period removes this dormancy, however, and by early February, buds are largely in a state of imposed dormancy with active growth commencing as soon as the temperature is high enough *(14).*

Specific gravity of balsam poplar wood ranges from 0.326 to 0.346 and differs among sites. Within individual trees, specific gravity varies from 0.318 to 0.429 and is greatest at the top of the tree. Fiber length ranges from 1.02 mm (0.04 in) at breast height to 0.78 mm (0.03 in) at a bole position of 75 percent of total height. Sapwood pH averages 5.40 and heartwood 8.12. No significant differences were found among male and female clones in pH or wood and bark extractives. Lignin content of wood was higher in the sapwood than in the heartwood; bark lignin content was three times greater than that of the wood *(32,48).*

Balsam poplar stands are generally even-aged, with some variation. On upland sites in Saskatchewan, the greatest age span is about 17 years, but most stands have an age range of 5 years or less *(10).* Age spans are 20 to 25 years or less in young stands and 50 to 60 years in 155- to 165-year-old stands occupying flood plain sites in northeast British Columbia *(40).*

Figure *3-Mature* balsam *poplars 41 cm to 51 cm (16 to 20 in) in d.b.h. in Minnesota-bout 100 years old.*

The greatest age spans have been observed in the poplar groves characteristic of treeline stands. Clones in Alaska treeline stands have ramets ranging in age from 1 to more than 100 years old. New suckers tend to be produced at the periphery of the clone (35).

Stand density varies with stand history. The density of stems larger than 2.5 cm (1 in) varies from 8700/ha (3,250/acre) in 25-year-old stands to 225/ha (91/acre) in 200-year-old stands *(53).* In southern portions of the species' range, stand density is not well documented but is probably lower than in northern areas because balsam poplar does not normally occur in large pure stands. In Wisconsin, balsam poplar

Table l-Density and volume of balsam poplar in Saskatchewan by site type and drainage (adapted from 23)

Site type and drainage	Density			Volume		
	trees/ ha	trees/ acre	Pct of stand	m^2/ha	ft^2/acre	Pct of stand
White spruce-feathermoss, well drained	17	7	3	11	157	5
White spruce/ aspen-bunchberry, well drained	86	35	7	14	200	7
Aspen-hazelnut, well drained	91	37	12	22	314	10
Jack pine-feather-moss/club moss, moderately well drained	7	3	1	2	26	1
White spruce-feathermoss, moderately well drained	44	18	6	25	357	8

made up less than 2 percent of the total stand volume in the types where it was present (for example, balsam fir-white spruce, aspen, and tamarack) *(12)*. In mixed-wood sections, balsam poplar makes up 7 percent of the total volume and annual growth *(31)*, but this percentage varies with site type and drainage (table 1).

Total balsam poplar biomass estimates in Alaska range from 75 t/ha (33 tons/acre) in the Yukon River drainage to 180 t/ha (80 tons/acre) on the Tanana River flood plain for 60-year-old stands *(29,68)*. In Alberta, aboveground dry weight for trees 16 to 65 years old varied from 0.45 to 251 kg (0.99 to 553 lb); 33 to 71 percent of this weight was in the main stem *(30)*.

Forest survey reports for Alaska indicate that, in unmanaged stands, balsam poplar (or the hybrid with *P. trichocarpa*) has a mean annual increment of from 4 to 6 m^3/ha (57 to 86 ft^3/acre) in the Susitna Valley. Site indices (base age 100 years) in British Columbia range from 6 to 12 ft (low) to 34 to 42 ft (good) *(21)*.

Rooting Habit-On flood plains, the balsam poplar root system is multilayered, owing to the deposition of new soil by periodic flooding. Although early root development is downward, subsequent development progresses upward as root development occurs on the buried stem. In one instance, major new root development occurred at least six times as the initial root system and 2 m (6.6 ft) of the main bole were buried by silt deposition during a 30- to 40-year period *(40)*. Root development on the buried stem of seedlings occurs within several weeks of burial and appears to be associated with the presence of preformed root primordia *(8,34)*.

Expansion of the root system and subsequent sucker production can play an important role in clone development and colonization of a site after the seedling ortet becomes established. Extension of lateral roots 1 to 3 cm (0.4 to 1.2 in) in diameter has been observed to be at least 14 m (46 ft) in 15-year-old clones. Expansion of the root system ranged between 0.5 and 8.0 m (1.6 and 26 ft) in a 15-year-old clone; maximum rate of expansion occurred between 5 and 9 years (33). Root system expansion determined from clone size and age appears to be lower at treeline than at lower elevations where clones of about the same size occur but are 6 to 10 times older *(6,33,35)*.

On sites without active soil deposition, formation of the root system is predominantly downward and lateral. Depth of rooting is restricted on the relatively wet sites where balsam poplar is commonly found. Lateral root spread on upland sites is at least 8 to 12 m (26 to 39 ft).

Reaction to Competition-Balsam poplar shows all the characteristics of an early successional species: that is, low shade tolerance, rapid juvenile growth, prolific seed production, relatively short life span, good self-pruning, and replacement by more tolerant associates. It is most accurately classed as very intolerant of shade.

In primary succession on river flood plains, balsam poplar is an early invader and is associated with various willows and alder for about 20 years after formation (53). It appears to assume dominance as a result of greater stature and relative growth rate than willow and alder, which precede it in succession, and white spruce, which follows it (58,591. It may have an allelopathic effect on alder germination and germinant development, but these effects have not been substantiated under field conditions *(27,58,59)*. Balsam poplar bud extracts inhibit nitrification under laboratory conditions, indicating the potential for nitrogen conservation within poplar stands and an effect on forest development and succession (49). It is the dominant species for about 50 years. White spruce gradually replaces balsam poplar, and by age 100 to 150 years, the poplar is a minor component of the stand. Deviations from this general pattern include the Yukon and Susitna Rivers where poplar stands more than 200 years old occur, and white spruce is a minor species present mainly in the understory.

Balsam poplar can be important in secondary succession on burns and cutovers or primary succession on lakeshores and sites severely disturbed by mining and construction. Asexual and sexual reproduction are important in burned and cutover areas, but only sexual reproduction is important on severely disturbed sites. Balsam poplar can reproduce asexually under stand conditions, but the suckers are short lived.

Damaging Agents-Susceptibility of balsam poplar to fire is determined by characteristics of individual trees and stands. Thickness of bark increases with age, giving increased resistance to fire; however, the bark of mature trees tends to be deeply fissured, and the protection afforded the cambium is less than if a continuous sheath surrounded it. Mature trees can withstand mild and perhaps moderately intense fires. Balsam poplar supports crown fires only under the severest burning conditions *(41).*

Fire fuels differ in the various vegetation types where balsam poplar occurs. Pure stands of balsam poplar support fires of less intensity than those in mixed conifer-hardwood stands, and tree survival is greater. Early successional stands containing only hardwoods are less likely to burn intensely than later successional stages or mixed balsam poplar-conifer stands *(41).* Balsam poplar produces root suckers after fire, and burned sites can be colonized by seed reproduction when mineral soil seedbeds are created.

As rivers create sites for establishment of balsam poplar, they also destroy sites with established stands. This process can be gradual as the river slowly undermines its bank at the rate of a few feet per year, or the erosion can be dramatic. It is not uncommon to see river channels change by 30 to 60 m (100 to 200 ft) in several years. These channel changes can destroy significant areas of established poplar stands.

Moose, deer, elk, and other animals browse on balsam poplar stem material but eat little foliage (3). Stems as large as 5 cm (2 in) d.b.h. may be broken by moose and the tops browsed. Where browsing occurs for only 1 or 2 years, however, form is not adversely affected because subapical buds rapidly replace damaged terminals. Simulated browsing of 9- to 14-year-old poplars resulted in increased twig biomass, indicating that only under the severest, repeated browsing is it adversely affected *(16).*

Resin of balsam poplar appears to repel snowshoe hares, and foliar buds have higher resin contents than internodes. As a result, hares may eat internodes of twigs and stems but not the buds *(3,38).* High terpene and phenolic resin content are sufficient to reduce cellulose digestion, making balsam poplar less palatable to animals (43).

Girdling by hares or rodents can kill saplings or small trees above the girdle, but dormant buds from below the girdle usually form a new stem. Ruffed grouse may feed on staminate buds in the winter.

Beaver frequently cut balsam poplar growing along watercourses; usually, sprouts are not produced or, if they are, they either die or are browsed and subsequently die. On small streams, ponds created by beaver clams can kill poplars growing in or adjacent to ponded areas.

The poplar and willow wood borer *(Cryptorhynchus lapathi)*, bronze poplar borer ***(Agrilus liargus),*** and the poplar borer ***(Saperda calcarata)*** are among the most damaging insects. They girdle or badly weaken trees larger than 2.5 cm (1 in) in diameter by tunneling in the main stem and limbs (9).

The forest tent caterpillar *(Malacosoma disstria)*, satin moth *(Stilpnotia salicis)*, gray willow leaf beetle *(Pyrrhalta decora decora)*, and aspen leaf beetle *(Chrysomela crotchi)* feed on balsam poplar foliage, but the species is not their principal host *(1).* The highly resinous buds and leaves of balsam poplar may render them relatively less palatable than the principal tree hosts (3).

In mature trees, the most common decay-causing fungal species is ***Phellinus tremulae*** with ***Pholiota destruens, Corticium expallens,*** and ***Bjerkandra adusta*** also being important. A canker caused by ***Neofabraea populi*** has been observed on balsam poplar in Ontario less than 3 cm (1.2 in) in diameter *(22,23).* The occurrence of decay varies with site conditions and among clones, with the latter appearing to be the most important cause of resistance (23). Infection by ***Rhytidiella moroformis*** causes a roughening of the normally smooth bark and the formation of deep furrows. ***Melampsora*** spp. cause a leaf rust and ***Linospora*** spp., a leaf blight (22). ***Venturia populina*** causes a leaf and twig blight and can stunt the main stem.

Septoria musiva and ***S. populicola*** cause a leaf spot and canker on balsam poplar seedlings. ***Septoria musiva*** was reported to cause the highest percentage of canker and leaf spot in southern Manitoba. *Septoria* incidence on native poplars within their range is negligible *(61).*

Frost damage occurs to trees of all ages in exposed stands established after burns and logging, in nursery stooling beds, and in plantations of hybrid poplar *(60).* Entire twigs may be shed. Distortion from frost damage occurs adjacent to cankers, and dieback results in burl formation, bud proliferation, sucker production, and uneven development of bark, leaf, and sapwood *(60).*

Special Uses

Natural stands are generally described as underutilized, but its use is increasing as hardwood utilization increases in the mixed-wood section of the boreal forest. Although the wood can be used for a variety of products (for example, pulp, veneer, core stock, boxes, crates, brackets), species such as aspen and cottonwood are preferred. Waferboard with excellent mechanical qualities can be produced from balsam poplar; however, special procedures are needed to efficiently waferize the wood *(17,421.* In northern areas, balsam poplar is used for structural lumber and milled house logs when other species are not available.

Balsam poplar hybrids have a potential for a variety of uses. *Populus balsamifera* X *P. deltoides (Populus x jackii)* are used as windbreak and shelterwood plantings in the northern plains region. Other balsam poplar hybrids are being tested in short rotation, intensive culture plantations. When properly cultivated, irrigated, and fertilized, these hybrids yield about three or four times as much biomass as native aspen in northern Wisconsin. The resulting pulpwood is of acceptable quality. The foliage and small woody component can be converted to an animal feed supplement *(26,70).*

Balsam poplar and its hybrids are used or have potential value in urban forestry and soil stabilization projects, particularly in the northern portion of the range and in the plains area of western Canada where the number of indigenous species available for these purposes is limited. In urban situations, however, balsam poplar has several undesirable traits. The branches of older trees tend to be brittle, female trees produce large amounts of residue from the spent catkins, and relatively rapid root suckering can result in unwanted colonization of lawns, sidewalks, and roadways.

Anyone that has ever walked into a poplar stand in the spring at bud break is impressed with the fragrance in the air. This fragrance comes from the volatile compounds in the buds and other parts of the tree. These compounds have been identified and may have useful biological and esthetic properties (38). Various extracts from the winter buds of poplar were recognized by native peoples as having therapeutic value. For example, a salve or ointment (balm of Gilead) made by heating the winter buds in oil was used to relieve congestion *(52).* In recent years, the bark has been collected and carved into figures that are sold in gift shops.

Genetics

Balsam poplar is in the section Tacamahaca of the genus *Populus* (24). Two varieties have been identified: the typical variety *Populus balsamifera* var. *balsamifera* and *P. balsamifera* var. *subcordata,* found in eastern Canada (2).

Balsam poplar and black cottonwood *(Populus trichocarpa)* have hybridized and produced mixed populations. Because of this intermixing, black cottonwood has been suggested as a subspecies (i.e., *Populus balsamifera* subsp. *trichocarpa) (2,371.* Where balsam poplar and black cottonwood overlap, hybrids with a range of characters intermediate to those of the two species are found. An index using capsule shape, capsule pubescence, and carpel number has been developed *(2,55).* Other hybrids have been reported between balsam poplar and *F! alba, F! laurifolia, l? nigra, I? simonii, P. sauveolens, P. tremula,* and *I? tristis (7,37,69).*

Literature Cited

1. Baker, W. L. 1972. Eastern forest insects. USDA Forest Service, Miscellaneous Publication 1175. Washington, DC. 642 p.
2. Brayshaw, T. C. 1966. The status of the black cottonwood (*Populus* trichocarpa Torr. and Gray). Canadian Field-Naturalist 79(2):91–95.
3. Bryant, J. P., and P. J. Kuropat. 1980. Selection of winter forage by subarctic browsing vertebrates: The role of plant chemistry. Annual Review of Ecology and Systematics 11:261–285.
4. Buch, T. G. 1961. Comparative study of biochemical characteristics in seeds of coltsfoot, poplar, and willow. Bulletin Glavnago Botanicheskogo Sada 41:66–73. [In Russian; translated by R. Ganns.]
5. Carleton, T. J., and P. F. Maycock. 1978. Dynamics of the boreal forest south of James Bay. Canadian Journal of Botany 56:1157–1173.
6. Comtois, P., J. P. Simon, and S. Payette. 1986. Clonal constitution and sex ratio in northern populations of balsam poplar. Holarctic Ecology 9(4):251–260.
7. Cram, W. H. 1960. Performance of seventeen poplar clones in south-central Saskatchewan. Forestry Chronicle 36(3): 204–208, 224.
8. Cunningham, T. W., and R. E. Farmer, Jr. 1984. Seasonal variation in propagability of dormant balsam poplar cuttings. Plant Propagator 30(1):13–15.
9. Davidson, A. G., and R. M. Prentice. 1968. Chapter VII. Insects and diseases. *In* Growth and utilization of poplars in Canada. p. 116-144. J. S. Maini and J. H. Cayford, eds. Departmental Publication 1205. Canada Department of Forestry and Rural Development, Forestry Branch, Ottawa, ON.
10. Dix, R. L., and H. M. A. Swan. 1971. The roles of disturbance and succession in upland forest at Candle Lake, Saskatchewan. Canadian Journal of Botany 49(5):657–676.

11. Ek, A. R., and D. H. Dawson. 1976. Actual and projected yields of ***Populus*** "Tristis" under intensive culture. Canadian Journal of Forest Research 6(2):132–144.
12. Essex, B. L., and J. T. Hahn. 1976. Empirical yield tables for Wisconsin. USDA Forest Service, General Technical Report NC-25. North Central Forest Experiment Station, St. Paul, MN. 22 p.
13. Eyre, F. H., ed. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC. 148 p.
14. Farmer, R. E., Jr., and R. W. Reinholt. 1986. Genetic variation in dormancy relations in balsam poplar along a latitudinal transect in northwestern Ontario. Silvae Genetica 35(1):38–42.
15. Farmer, R. E., Jr., R. W. Reinholt, and F. Schnekenburger. 1986. Environmental preconditioning and variance in early growth of balsam poplar. Silvae Genetica 35(4):129–131.
16. Fox, J. F., and J. P. Bryant. 1984. Instability of the snowshoe hare and woody plant interaction. Oecologia 63:128–135.
17. Gertjejansen, R. O., and D. J. Panning. 1985. Method for waferizing balsam poplar. Forest Products Journal 35(4):53–54.
18. Gill, D. 1971. Vegetation and environment in the Mackenzie River Delta, Northwest Territories: A study in subarctic ecology. Thesis (Ph.D.), University of British Columbia, Vancouver. 696 p.
19. Gordon, Allan G. [n.d.]. Personal communication. Ontario Ministry of Natural Resources, Sault Ste. Marie, Ontario (Dr. Gordon provided unpublished data of the late T. Angus Hills).
20. Hansen, E. A., H. A. McNeel, D. A. Netzer, and others. 1979. Short-rotation intensive culture practices for northern Wisconsin. *In* Proceedings, Annual Meeting of the North American Poplar Council, Aug. 14-17, 1979, Thompsonville, MI. p. 47-63.
21. Hegyi, F., J. Jelinek, and D. B. Carpenter. 1979. Site index equations and curves for the major tree species in British Columbia. British Columbia Ministry of Forests, Forest Inventory Report 1. Victoria. 7 p.
22. 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.
23. Hiratsuka, Y., and A. A. Loman. 1984. Decay of aspen and balsam poplar in Alberta. Environment Canada, Northern Forest Research Centre, Information Report NOR-X-262. 19 p.
24. Holloway, Patricia, and John C. Zasada. 1979. Vegetative propagation of 11 common Alaska woody plants. USDA Forest Service, Research Note PNW-334. Pacific Northwest Forest and Range Experiment Station, Portland, OR. 12 p.
25. Institute of Northern Forestry. 1983. Unpublished data. USDA Forest Service, Fairbanks, AK.
26. Isebrands, J. G., J. A. Sturos, and J. B. Crist. 1979. Integrated utilization of biomass. A case study of short-rotation intensively cultured ***Populus*** raw material. Tappi 62(7):67–70.
27. Jodibon, R., and J. R. Thibault. 1981. Allelopathic effects of balsam poplar on green alder germination. Bulletin of the Torrey Botanical Club 108(4):413–418.
28. Johnson, L. 1983. Personal communication. U.S. Army Cold Regions Research and Engineering Laboratory, Fairbanks, AK.
29. Johnson, P.-L., and T. C. Vogel. 1966. Vegetation of the Yukon Flats Region, Alaska. Cold Regions Research and Engineering Laboratory Research Report 209. U.S. Army Material Command, Hanover, NH. 53 p.
30. Johnstone, W. D., and C. B. Peterson. 1980. Above ground component weights in Alberta ***Populus*** stands. Environment Canada. Northern Forest Research Centre, Information Report NOR-X-226. Edmonton, AB. 18 p.
31. Kabzems, A., A. L. Kosowan, and W. C. Harris. 1976. Mixed-wood section in an ecological perspective—Saskatchewan. Saskatchewan Department of Tourism and Renewable Resources, Forestry Branch, Technical Bulletin 8. Regina, SK. 118 p.
32. Kellogg, R. M., and E. P. Swan. 1986. Physical properties of black cottonwood and balsam poplar. Canadian Journal of Forest Research 16(3):491–496.
33. Krasny, M. E., K. A. Vogt, and J. C. Zasada. 1988. Establishment of four Salicaceae species on river bars in interior Alaska. Holarctic Ecology 11(3):210–219.
34. Krasny, M. E., J. C. Zasada, and K. A. Vogt. 1988. Adventitious rooting of four Salicaceae species along the Tanana River, Alaska. Canadian Journal of Botany 66:2597–2598.
35. Lev, D. J. 1987. Balsam poplar ***(Populus balsamifera)*** in Alaska: Ecology and growth response to climate. Thesis (MS), University of Washington, Seattle. 70 p.
36. Maini, J. S. 1966. Apical growth of Populus spp. I. Sequential pattern of internode, bud, and branch length of young individuals. Canadian Journal of Botany 44(5):615–622.
37. Maini, J. S., and J. H. Cayford, eds. 1968. Growth and utilization of poplars in Canada. Canada Department of Forestry and Rural Development, Forestry Branch Publication 1205. Ottawa, ON. 257 p.
38. Mattes, B. R., T. P. Clausen, and P. B. Reichardt. 1987. Volatile constituents of balsam poplar: The phenol glycoside connection. Phytochemistry 26(5):1361–1366.
39. Morris, D. M., and R. E. Farmer. 1985. Species interactions in seedling populations of ***Populus tremuloides*** and ***P. balsamifera:*** Effects of density and species ratios. Canadian Journal of Forest Research 14:593–595.
40. Nanson, G. C., and H. F. Beach. 1977. Forest succession and sedimentation on a meandering river floodplain, northeast British Columbia, Canada. Journal of Biogeography 4:229–251.
41. Norum, Rodney A. 1983. Personal communication. USDA Forest Service, Institute of Northern Forestry, Fairbanks, AK.
42. Panning, D. J., and R. 0. Gertjejansen. 1985. Balsam poplar as a raw material in waferboard. Forest Products Journal 35(5):47–54.
43. Risenhoover, K. L., L. A. Renecker, and L. E. Morgantini. 1985. Effects of secondary metabolites from balsam poplar and paper birch on cellulose digestion. Journal of Range Management 38(4):370–372.
44. Roe, E. I. 1958. Silvical characteristics of balsam poplar. USDA Forest Service, Station Paper 65. Lake States Forest Experiment Station, St. Paul, MN. 17 p.
45. Rowe, J. S. 1972. Forest regions of Canada. Canadian Forestry Service, Publication 1300. Ottawa, ON. 172 p.
46. Schier, G.A., and Robert B. Campbell. 1976. Differences among ***Populus*** species in ability to form adventitious shoots and roots. Canadian Journal of Forest Research 6(3):253–261.

47. Schreiner, Ernest 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.
48. Swan, E. P., and R. M. Kellogg. 1986. Chemical properties of black cottonwood and balsam poplar. Canadian Journal of Forest Research 16(3):497–501.
49. Thibault, J. R., J. A. Fortin, and W. A. Smirnoff. 1982. In vitro allelopathic inhibition of nitrification by balsam poplar and balsam fir. American Journal of Botany 69(5):676–679.
50. Van Cleve, K., and L. A. Viereck. 1981. Forest succession in relation to nutrient cycling in the boreal forest of Alaska. *In* Forest succession: Concepts and application. p. 185-210. D.C. West, H. H. Shugart, and D. B. Botkin, eds. Springer-Verlag.
51. Van Cleve, Keith, C. T. Dyrness, and L. A. Viereck. 1980. Nutrient cycling in interior Alaska flood plains and its relationship to regeneration and subsequent forest development. *In* Forest regeneration at high latitudes. p. 11-18. Mayo Murray and Robert M. VanVeldhuizen, eds. USDA Forest Service, General Technical Report PNW-107. Pacific Northwest Forest and Range Experiment Station, Portland, OR.
52. Viereck, E. G. 1987. Alaska's wilderness medicines—healthful plants of the far north. Alaska Northwest Publishing Company, Edmonds, WA. 107 p.
53. Viereck, L. A. 1970. Forest succession and soil development adjacent to the Chena River in interior Alaska. Arctic and Alpine Research 2(1): l-26.
54. Viereck, L. A. 1979. Characteristics of treeline plant communities in Alaska. Holarctic Ecology 2(4):228–238.
55. Viereck, Leslie A., and Joan M. Foote. 1970. The status of *Populus balsamifera* and *P. trichocarpa* in Alaska. Canadian Field-Naturalist 84(2):169–173.
56. 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.
57. Viereck, L. A., C. T. Dyrness, K. Van Cleve, and M. J. Foote. 1983. Vegetation, soils, and forest productivity in selected forest types in interior Alaska. Canadian Journal of Forest Research 13:703–720.
58. Walker, L. R., and F. S. Chapin. 1986. Physiological controls over seedling growth in primary succession on an Alaskan flood plain. Ecology 67(6):1508–1523.
59. Walker, L. R., J. C. Zasada, F. S. Chapin III. 1986. The role of life history processes in primary succession on an Alaska flood plain. Ecology 67:1243–1253.
60. Zalasky, H. 1975. Frost damage in poplar on the prairies. Forestry Chronicle 52(2):61–64.
61. Zalasky, H. 1978. Stem and leaf spot infections caused by *Septoria musiva* and *S. populicola* on poplar seedlings. Phytoprotection 59(1):43–50.
62. Zasada, J. C., and R. A. Densmore. 1977. Changes in seed viability during storage for selected Alaskan Salicaceae. Seed Science and Technology 5:509–518.
63. Zasada, J. C., and R. Densmore. 1980. Alaska willow and balsam poplar seed viability after 3 years. Tree Planters' Notes 31(2):9–10.
64. Zasada, J. C., and L. A. Viereck. 1975. Effect of temperature and stratification on germination of Alaska Salicaceae. Canadian Journal of Forest Research 5:333–337.
65. Zasada, J. C., P. Holloway, and R. Densmore. 1977. Considerations for the use of hardwood stem cuttings in surface management programs. *In* Proceedings, Symposium on Surface Protection Through Prevention of Damage: Focus on the Arctic Slope. p. 148-157. May 17-20, 1977. U.S. Department of Interior, Bureau of Land Management, Alaska State Office, Anchorage, AK.
66. Zasada, J. C., R. A. Norum, C. E. Teutsch, and R. Densmore. 1987. Survival and growth of planted black spruce, alder, aspen, and willow on a black spruce site in Interior Alaska. Forestry Chronicle 63:84–88.
67. Zasada, J. C., R. A. Norum, R. M. VanVeldhuizen, and C. E. Teutsch. 1983. Artificial regeneration of trees and tall shrubs in experimentally burned upland black spruce/feathermoss stands in Alaska. Canadian Journal of Forest Research 13:903–913.
68. Zasada, J. C., K. Van Cleve, R. A. Werner, and others. 1977. Forest biology and management in high latitude North American forests. *In* Proceedings, Symposium on North American Forest Lands at Latitudes North of 60 Degrees. p. 137-195. University of Alaska, Fairbanks, AK.
69. Zasada, J. C., L. A. Viereck, M. J. Foote, and others. 1981. Natural regeneration of balsam poplar following harvesting in the Susitna Valley, Alaska. Forestry Chronicle 57(2):57–65.
70. Zavitkovski, J., J. G. Isebrands, and D. H. Dawson. 1976. Productivity and utilization of short-rotation *Populus* in the Lake States. *In* Proceedings, Symposium on Eastern Cottonwood and Related Species. p. 392–401. B. A. Thielges, and S. B. Land, Jr., eds. Louisiana State University, Department of Continuing Education, Baton Rouge.