Thuja occidentalis L. Northern White-Cedar

Cupressaceae Cypress family

William F. Johnston

Northern white-cedar *(Thuja occidentalis)* is also called eastern white-cedar, arborvitae, and swamp-cedar. The name arborvitae or "tree of life" dates from the 16th century when the French explorer Cartier learned from the Indians how to use the tree's foliage to treat scurvy A record tree in Michigan measures 175 cm (69 in) in d.b.h. and 34 m (113 ft) in height. The rot- and termite-resistant wood is used principally for products in contact with water and soil. The tree provides valuable shelter and browse in winter deeryards, and it is a widely planted ornamental.

Habitat

Native Range

The main range of northern white-cedar (fig. 1) extends through the southern part of the eastern half of Canada and the adjacent northern part of the United States. Specifically, it extends westward from Anticosti Island in the Gulf of St. Lawrence to the southern part of James Bay and through central Ontario to southeastern Manitoba; then south through central Minnesota and Wisconsin to a narrow fringe around the southern tip of Lake Michigan; then east through southern Michigan, southern New York, central Vermont and New Hampshire, and Maine. The species also grows locally in northwestern Ontario, west-central Manitoba, southeastern Minnesota, southern Wisconsin, north-central Illinois, Ohio, southern New England, and in the Appalachian Mountains from western Pennsylvania south to western North Carolina and eastern Tennessee.

Climate

Northern white-cedar grows in a relatively humid climate. Annual precipitation commonly ranges from 710 to 1170 mm (28 to 46 in), but the extremes range from about 510 mm (20 in) at the tree's northern and western limits to 1400 mm (55 in) in the southern Appalachians. One-third to one-half of the precipitation occurs during the warm season. Snowfall ranges from about 100 cm (40 in) to more than 380 cm (150 in) annually.

Temperatures are often cool during a moderately short growing season. The northern limit of the range extends to the forest-tundra transition (subarctic zone) in Canada. The southern limit has an average annual temperature of less than 10" C (50" F) in the Lake States and up to 16" C (60" F) in the southern Appalachians. Average January temperatures commonly range from -12" to -4" C (10° to 24" F) and those of July from 16" to 22" C (60" to 72" F). The average frost-free period commonly ranges from about 90 to 180 days, but the extremes range from less than 80 days at the tree's northern limit to about 200 days in the southern Appalachians (16).

Soils and Topography

Northern white-cedar grows on a wide variety of organic soils (Histosols) and mineral soils (especially Inceptisols and Entisols); however, it does not develop well on extremely wet or extremely dry sites. It is most often associated with cool, moist, nutrient-rich sites, particularly on organic soils near streams or other drainageways, or on calcareous mineral soils. In Minnesota, however, white-cedar stands on uplands are primarily determined by an interaction of vegetation and lack of disturbance *(21).* Northern white-cedar commonly grows on soils ranging from pH 5.5 to 7.2 *(9,36).*

Northern white-cedar is usually dominant in rich swamps (forested rich fens) that have a strong flow of moderately mineral-rich soil water. The organic soil (peat) is usually moderately to well decomposed, 0.3 to 1.8 m (1 to 6 ft) thick, and often contains much rotted wood. It can also dominate the peat ridges in bog and fen complexes that have a sluggish movement of weakly enriched water *(22).*

On mineral soil (upland) sites northern white-cedar is characteristic of seepage areas, limestone uplands, and old fields. It is common on shallow loam over broken limestone in southeastern Ontario and often forms pure stands in old fields and pastures on moist, well-drained soils in Maine *(9),* southern Quebec, and southeastern Ontario. The tree also grows on calcareous clays, limestone cliffs, outcrops of acidic trap rock, and sandstone bluffs (10,291.

Northern white-cedar generally grows best on limestone-derived soils that are neutral or slightly alkaline and moist but well drained. Nevertheless, most commercial stands are in swamps, where northern white-cedar can compete well with its associates *(13)* and is normally protected from fire (23). Al-

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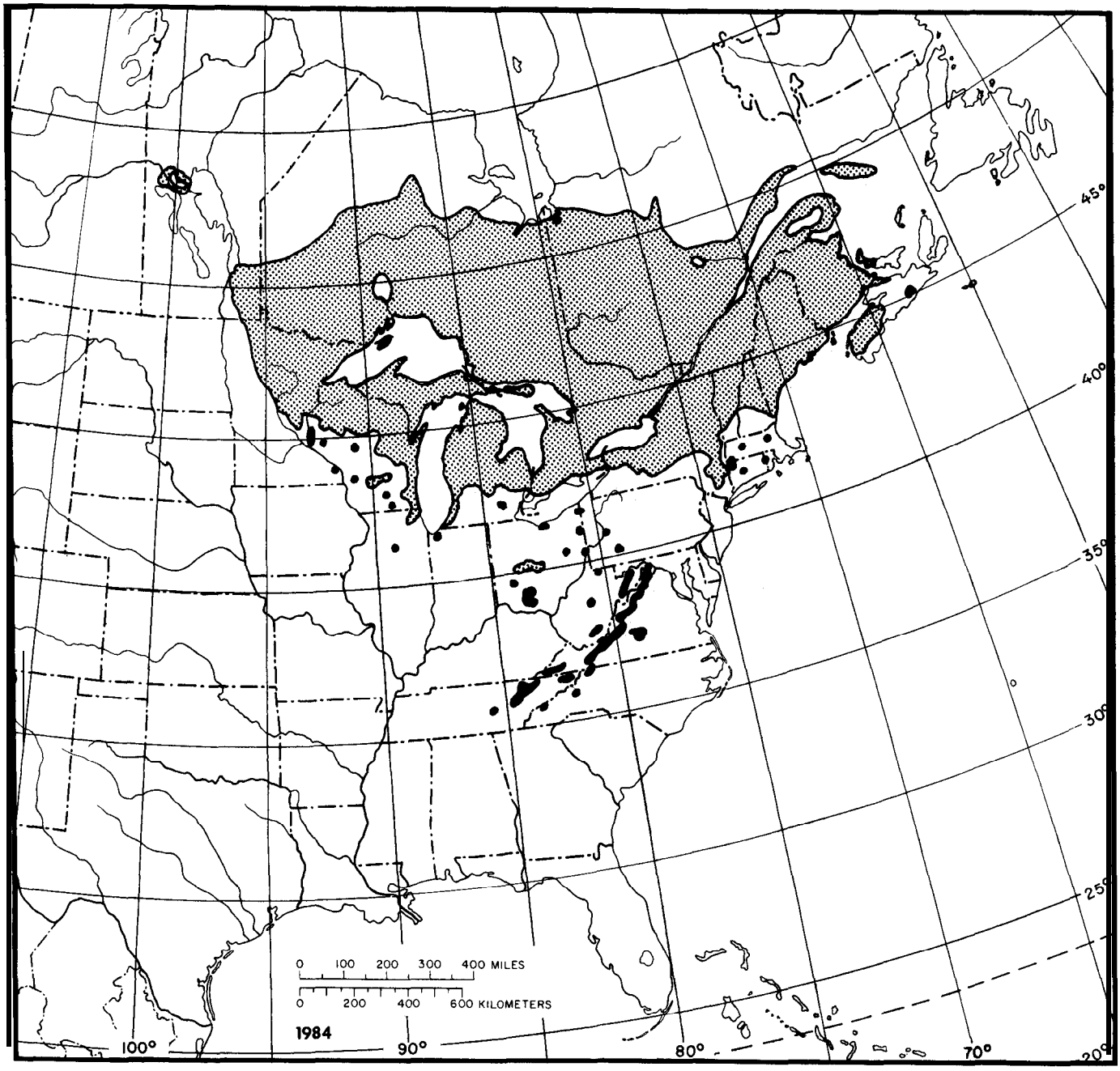

Figure *l-The native range of northern white-cedar.*

though old-field soils differ greatly, the tree's form and volume growth are much better on old fields than in poorly drained swamps *(9).*

Northern white-cedar grows from near sea level to more than 600 m (2,000 ft), but within most of its

range it is found between 150 and 600 m (500 and 2,000 ft).

Associated Forest Cover

Northern white-cedar most commonly grows in mixed stands but is also found in pure stands. It comprises a majority of the stocking or is pure in the Northern White-Cedar forest cover type (Society of American Foresters Type 37) and is an associate species in the following types *(13)*:

5	Balsam Fir
12	Black Spruce
13	Black Spruce-Tamarack
21	Eastern White Pine
23	Eastern Hemlock
24	Hemlock-Yellow Birch
30	Red Spruce-Yellow Birch
32	Red Spruce
33	Red Spruce-Balsam Fir
35	Paper Birch-Red Spruce-Balsam Fir
38	Tamarack
39	Black Ash-American Elm-Red Maple
108	Red Maple

The northern white-cedar type commonly includes some balsam fir *(Abies balsamea)* and tamarack *(Larix laricina)* in the boreal region of Canada but tends to be mixed with additional species farther south. Balsam fir, black spruce *(Picea mariana)*, white spruce *(P. glauca)*, red spruce *(P. rubens)*, tamarack, black ash ***(Fraxinus nigra)***, and red maple *(Acer rubrum)* are common associates on the wetter sites, especially swamps. Yellow birch ***(Betula alleghaniensis),*** paper birch *(B.* ***papyrifera),*** quaking aspen *(Populus* ***tremuloides),*** bigtooth aspen *(P. grandidentata),* balsam poplar *(P.* ***balsamifera),*** eastern hemlock ***(Tsuga canadensis),*** and eastern white pine *(Pinus strobus)* are common on the better drained sites, especially uplands.

Except when dense, northern white-cedar stands usually have an undergrowth of shrubs and herbs. Speckled alder *(Alnus rugosa)* is commonly the most important shrub on the better sites. Other characteristic shrubs on the better sites (especially in swamps) include mountain maple *(Acer spicatum)*, red-osier dogwood *(Cornus* ***stolonifera),*** and fly honeysuckle *(Lonicera* ***canadensis).*** On poorer sites they include Labrador-tea ***(Ledum groenlandicum),*** blueberries *(Vaccinium* spp.), and wintergreen (teaberry) ***(Gaultheria procumbens)***; creeping snowberry *(G.* ***hispidula)*** is common on both kinds of sites (see 16 for a more complete list). Characteristic herbs on the better sites (especially in swamps) include dwarf raspberry *(Rubus pubescens)*, false lily-of-the-valley ***(Maianthemum canadense),*** woodfern *(Dryopteris* spp.), and bunchberry *(Cornus* ***canadensis).*** On poorer sites they include false Solomons-seal ***(Smilacina trifolia)*** and pitcherplant ***(Sarracenia purpurea)***. Ground cover is usually a mosaic of sphagnum ***(Sphagnum*** spp.) and other mosses, liverworts, decaying logs, and litter *(13)*.

Life History

Reproduction and Early Growth

Flowering and Fruiting-Male and female flowers of northern white-cedar, a monoecious species, are usually borne on separate twigs or branchlets; they are tiny, terminal, conelike bodies. Male flowers are yellowish and arise from branchlets near the base of the shoot; female flowers are pinkish and appear at the tips of short terminal branchlets. Ripe cones are pale cinnamon brown, oblong, and 8 to 13 mm (0.3 to 0.5 in) long.

In northeastern Minnesota, flower buds, which form during autumn, begin to expand the following spring from about mid-April to early May; pollen dispersal begins from late April to early June *(1)*. In northern Michigan flowering occurs from late April to early May, pollinated conelets begin to grow rapidly in late June, cones are full grown by mid-August, and cones ripen from August to September *(16,34,41)*. The period between cone ripening and cone opening is only from 7 to 10 days.

Seed Production and Dissemination-Cone production has been induced within 3 months of seed germination using gibberellic acid and a long photoperiod *(18)*. Under normal conditions cones have been found on northern white-cedars as young as 6 years old (9). Seed production in large quantities begins when the trees are about 30 years old but is best after 75 years. An average-sized tree with a fairly full crown can produce about 9 liters (0.25 bu) of cones *(16)*, yielding 60,000 to 260,000 cleaned seeds. Limited data from Michigan indicate that white-cedar trees on upland sites produce more cones per tree, more seeds per cone, and a higher percentage of full seeds than those on swamp sites (6).

Rangewide, northern white-cedar generally bears good or better seed crops at intervals of 2 to 5 years. However, during a 26-year period (1949–74) in northeastern Wisconsin, such crops were produced every 1 to 3 years, with medium crops to failures in the intervening years. In addition, it was found that good or better white-cedar seed crops can be predicted by similar-sized crops in red maple the preceding spring *(20)*.

Seed dispersal usually begins in September, although it sometimes begins as early as August. In the northern Lake States cones open from mid-September to late October *(1,411.* Most of the seeds are released by November, but some seeds continue to fall throughout the winter.

Northern white-cedar seeds are light chestnut brown, about 6 mm (0.25 in) long, and have lateral wings about as wide **as** the body; cleaned seeds average 763,000/kg (346,000/lb) *(41).* Most seed is wind disseminated, with the seeding range estimated to be from 45 to 60 m (150 to 200 ft) under normal conditions *(16).*

Seedling Development-Northern white-cedar seeds remain viable for 5 years or more when stored in sealed containers at 6 to 8 percent moisture content and 0" to 3" C (32" to 38" F). As a rule the seeds have only slight internal dormancy Under forest conditions dormancy is broken while the seeds lie on the ground during the first winter; thus fall sowing is generally recommended (41). Because white-cedar seeds apparently do not remain viable in the forest floor longer than 1 year, such seeds should not be relied on for reproduction after clearcutting or fire *(6,17).*

Germination is epigeal, with the cotyledons rising above the ground. The seed seems to germinate best at high temperatures such as 29" C (84" F) *(19),* so that even though germination normally begins in May or June of the year following seed dispersal, it sometimes does not occur until late July or early August. Alternating day and night temperatures of 30" and 20" C (86" and 68" F), respectively, are recommended for germination tests (41).

Northern white-cedar seeds germinate readily on a variety of moist substrates, but seedlings become established on only a few. The main requirements for early development seem to be a constant moisture supply and warm temperatures *(10,19).* Although white-cedar generally grows best on neutral or slightly alkaline soil, seedlings do best on neutral or slightly acid soil but will grow on slightly alkaline soil (16). On cutover white-cedar swamps in Minnesota, seedlings were found only where the pH of the surface soil (upper 10 cm or 4 in) ranged from 6.6 to 7.2 *(36).*

On undisturbed areas, seedbeds of decaying (rotten) wood of logs and stumps account for more than 70 percent of the seedlings *(10,25).* These seedbeds usually are more moist, warmer, and have less litter than other seedbed types *(19);* they are also commonly dominated by mosses such as *Heterophyllium, Pleurozium,* and *Brotherella (25).* Some seedlings become established-but usually much less frequently-on decayed litter, peat or humus, and sphagnum moss.

On disturbed areas, northern white-cedar seedlings commonly prosper on both upland and swamp burns. Broadcast burning (or wildfire) apparently must be fairly severe, however, to expose favorable, mineral soil seedbeds on uplands or to improve moss seedbeds in swamps *(27,48).* White-cedar seedlings also reproduce well on skid roads where the compacted moss stays moist *(16).* A heavy cover of slash hinders seedling establishment, but a light cover is more favorable than none (27,481.

Northern white-cedar seedlings generally grow slowly under both forest and nursery conditions. Annual height growth averages only about 8 cm (3 in) during the first several years; seedlings can grow this much in 140 days under long photoperiods in growth chambers *(18).* Stock raised in a nutrient solution and hardened in a nursery was superior to S-year-old (2-l) nursery transplants (49). In upland plantings transplants averaged 0.9 m (2.9 ft) tall at 9 years of age in the northern Lake States and 2.6 m (8.5 ft) tall at 12 years in Illinois *(26,29).*

Although moisture is often the most important factor during the first few years, ample light is needed for continued seedling development. Seedlings were tallest when grown in about half of full light, but their shoots and roots were heaviest in full light *(31).* In areas with frequent hot, dry spells, partial overstory shade is necessary to reduce losses from drought and herbaceous competition *(19).*

Both shoot and radial growth generally begin in May and end by late August or in September in the northern Lake States and New Brunswick *(1,161.*

Mortality of northern white-cedar seedlings during their early years is extremely high. Drought is probably the most important cause; seedlings on substrates such as thick moss, stumps, and hummocks often dry out during the summer. Other causes of early loss or damage include smothering by sphagnum moss or logging slash, cutting or girdling by small rodents such as the red-backed vole, and deer browsing (especially on planted stock) *(9,16,26,49).*

Vegetative Reproduction-Northern white-cedar can send out roots from any part of a branch or stem if moisture conditions are favorable. Thus it frequently reproduces vegetatively in swamps, especially on poor sites with abundant sphagnum moss. If young seedlings are not considered, many more stems probably originate vegetatively than from seed in most swamps because vegetative reproduction is more tolerant of shade and is never without an adequate root system (9).

Layering generally accounts for more than half the stems of white-cedar reproduction in northern Michigan and Maine swamps. It is most common in young stands and those with leaning trees, where the lower branches become covered by moss. Seedlings may produce layerings by age 5 or before *(16,34)*.

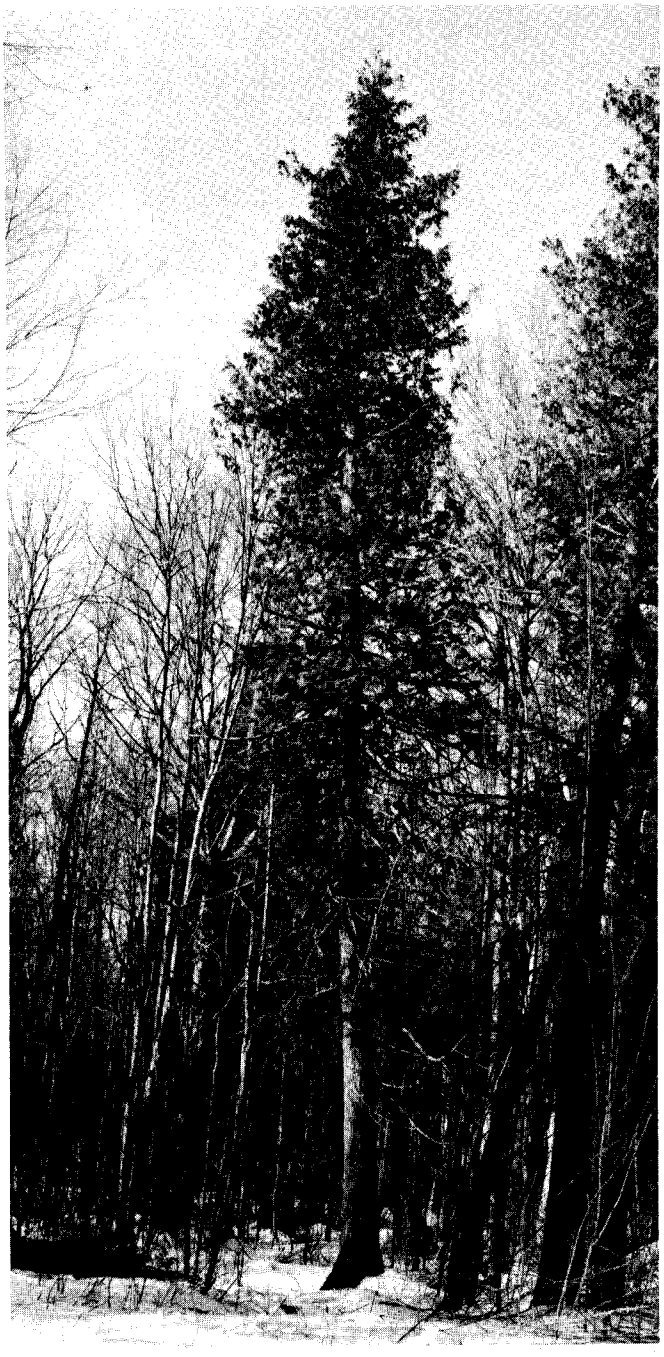

Figure *2-A mature northern white-cedar on an upland site in northern Minnesota.*

New trees also develop vegetatively from uprooted trees whose vertical branches form roots. Sprouts from roots or stumps are generally rare *(16)*. Cuttings are commonly used to propagate cultivars of northern white-cedar; under forest conditions branchlets may be rooted by setting them out in deep sphagnum moss (9).

Sapling and Pole Stages to Maturity

Growth and Yield-Northern white-cedar is a medium-sized tree, commonly 12 to 15 m (40 to 50 ft) tall and 30 to 60 cm (12 to 24 in) in d.b.h. at maturity (tig.2). Infrequently it reaches 21 to 24 m (70 to 80 ft) tall and 120 to 150 cm (48 to 60 in) in d.b.h. (10). Maximum dimensions reported are more than 30 m (100 ft) in height and 180 cm (72 in) in d.b.h. White-cedar reaches a maximum age of 400 years or more in swamps or on other lowland sites *(16)*.

The growth rate of northern white-cedar is greatly affected by site productivity and is expressed as site index or the height of dominants at age 50 years. In the Lake States, site index ranges from about 12 m (40 ft) on the best sites to 5 m (15 ft) on the poorest (27). Indications are that the site productivity of white-cedar swamps could be increased substantially by drainage *(44)*. Northern white-cedar generally grows more slowly and attains less height than associated trees, especially in swamps.

Information on yield of northern white-cedar is limited mainly to normal yield tables for pure, fully stocked, even-aged stands in the Lake States (fig. 3). Such stands have yields at 120 years as shown in table 1 (27).

Northern white-cedar reaches a maximum basal area of about 69 m^2/ha (300 ft^2/acre) *(8)*. Unfortunately for its value as timber, the tree commonly has a curved butt and poor form, especially in swamps (9).

Little is known about biomass production, although components of various-sized white-cedars have been analyzed for weight (and nutrient elements) *(12)*. Above-ground biomass in one 70- to 100-year-old white-cedar stand totaled 159 t/ha (71 tons/acre) and had a net annual productivity of about 10 t/ha (4.5 tons/acre) (38).

Timber rotations for northern white-cedar differ greatly with site productivity and management objective. Rotations for maximizing merchantable cubic volume range from 70 to 90 years for a site index of 12 m (40 ft) and from 80 to 100 years for an index of 9 m (30 ft). Rotations for sawtimber range from 110 to 140 years for a site index of 12 m (40 ft) and from 130 to 160 years for an index of 9 m (30 ft) (27).

Table l-Characteristics of fully stocked, even-aged stands of northern white-cedar in the Lake States *(27)*

Item	Site index at base age 50 years	
	9 m or 30 ft	12 m or 40 ft
Height of dominants and codominants, m	15	21
D.b.h., cm[1]	23	31
Trees/ha[1]	1112	618
Basal area, m^2/ha[1]	45	47
Merchantable volume, m^3/ha[2]	244	319
Sawtimber volume (Scribner), m^3/ha[3]	129	279
Height of dominants and codominants, ft	50	69
D.b.h., in[1]	8.9	12.4
Trees/acre[1]	450	250
Basal area, ft^2/acre[1]	195	205
Merchantable volume, ft^3/acre[2]	3,480	4,560
Sawtimber volume (Scribner) fbm/acre[3]	9,220	19,900

[1] Trees 0.25 cm (0.1 in) and larger in d.b.h.
[2] Peeled volume for trees 13 cm (5.0 in) and larger in d.b.h.
[3] Volume for trees 23 cm (9.0 in) and larger in d.b.h.

Figure *3-A mature stand of northern white-cedar on a swamp site in northern Minnesota.*

Rooting Habit-Northern white-cedar seedlings grown in different soil media have shown that as moisture-holding capacity increases, root form changes from a long taproot with few laterals to shorter, thicker roots with many laterals. Root extension is particularly pronounced in rotten wood (9). In Wisconsin, seedlings grown from seed collected in upland stands developed deep root systems in well-drained soils and shallow root systems in saturated soils; their lowland counterparts showed little plasticity in root development (33).

After the seedling stage northern white-cedar generally develops a shallow, wide-spreading root system; and natural root grafts are fairly common. Because the tree grows on rocky cliffs throughout its range, the root system is apparently well adapted to secure water and nutrients from cracks in rocks *(10).*

Reaction to Competition-Northern white-cedar is classed as shade tolerant, but it has been placed in three classes: very tolerant, tolerant, and intermediate. This variation probably exists because vegetative reproduction is considered more tolerant than seedlings *(9).* Northern white-cedar is less tolerant than balsam fir but slightly more tolerant than black spruce. White-cedar can withstand severe suppression for several years, and it responds well to release not only during the reproduction period but at nearly all ages *(3,16).*

Response to thinning northern white-cedar depends upon site quality, residual stand density, and stand age. In a well-drained Michigan swamp, a 45-year-old stand with a residual basal area of 15.8 m^2/ha (69 ft^2/acre) more than doubled its basal area in 8 years following thinning; a similar thinning in a poorly drained swamp showed no beneficial effect *(16).* In a 65-year-old stand on a medium swamp site in Wisconsin, basal area growth following a second thinning was independent of stand density over a wide range. The growth rate decreased following the second thinning, however, probably because of increasing stand age *(14).*

Both even-aged and uneven-aged stands of northern white-cedar are common. Even-aged stands develop in large swamp openings following wildfire or clearcutting *(13).* In Wisconsin white-cedar often invades speckled alder thickets that form in swamps following wildfire or changes in water level; and it can reproduce directly on burned peat *(10).* Even-aged stands also develop on abandoned upland fields in Maine (and southeastern Canada&but apparently only where competition is not severe (9).

Uneven-aged white-cedar stands are generally associated with the late stages of succession and are found mainly in swamps or on other moist sites (23).

They develop where white-cedar reproduces in small openings created by partial cutting or wind damage, especially on poor sites where reproduction is mainly of vegetative origin. Uneven-aged stands also develop where white-cedar gradually succeeds associates—such as balsam poplar, tamarack, and black spruce—that are not as shade tolerant or long-lived *(13).* However, understory white-cedars sometimes are not much younger than the overstory species; in such cases what appears to have developed through succession may really be due to suppression (23).

Without major disturbance such as fire, the northern white-cedar type is exceedingly stable because the tree is long-lived and balsam fir is the only important associate sufficiently shade tolerant to grow in dense white-cedar stands *(10).* Many stands, however, have been either opened by timber harvesting or severely browsed by white-tailed deer. In both cases, succession is often to balsam fir or swamp hardwoods, especially black ash (27).

In Michigan's Upper Peninsula, northern white-cedar reproduction was most abundant after clearcutting in small blocks and narrow strips, and it should grow best after such cutting because hardwood competition is less than after partial cutting (3). Shelterwood cutting is preferred, however, for the last blocks or strips to ensure adequate natural seeding (27). This method of cutting also provides the partial overstory shade necessary to reproduce white-cedar in areas with frequent hot, dry spells *(19).*

Successful deeryard management requires reproducing large, even-aged stands of white-cedar (47). Because deeryard management and timber management are usually inseparable in the white-cedar type, the general recommendation is to produce large patches-16 to 65 ha (40 to 160 acres)—by harvesting small blocks annually *(48),* using clearcutting or shelterwood cutting as indicated above. Satisfactory reestablishment of white-cedar after clearcutting, however, often requires some kind of site preparation, particularly broadcast burning of slash (48). Where winter deer densities are high, the entire patch must be completely cleared in 10 years or less to minimize overbrowsing *(27);* but where they are low, small blocks or narrow strips may be clearcut at 30-year intervals (42).

Damaging Agents-On wet sites such as swamps, restricted soil aeration resulting from abnormally high water levels usually reduces the growth rate of northern white-cedar and may kill entire stands. Wetland road crossings and beaver damming are the primary causes of flooding. Road-caused flooding has killed white-cedar or reduced its growth on thousands of hectares in northern Minnesota (45); natural gas and petroleum pipelines will probably have similar effects unless cross drainage is provided (4).

Wind-induced uprooting and breakage sometimes occur in older stands on both upland and swamp sites, especially along exposed edges and in stands opened by partial cutting (27). Large trees and those with basal defect are most susceptible to wind damage.

Northern white-cedar is highly susceptible to fire damage because its bark is thin and has a high oil content; its shallow roots are easily damaged even by light ground fires (6). On the Laurentian Shield in northeastern Minnesota, this species has been driven to the lakeshores by fire (23). The risk of wildfire is low, however, on most white-cedar areas in the United States and good fire protection now results in little loss (27).

Snow and ice often damage northern white-cedar by breaking limbs (6); they also break stems or force trees into a permanent leaning position *(7,9).*

Agents that turn northern white-cedar foliage yellow or brown and sometimes cause severe damage or death include unfavorable winter weather, deicing salts, and drought. Plantings are particularly susceptible to winterkill caused by dehydration (40). The tree's tolerance of deicing salts is only moderate or intermediate *(15,46);* so branches exposed to salt spray along highways commonly have severe dieback. In Iowa windbreaks, white-cedar had more drought damage than other evergreens during a very dry winter (37). When the oldest foliage turns rusty red in the fall, however, it is a natural shedding of branchlets (cladoptosis) (39).

Northern white-cedar is relatively free from serious insect injury *(9,39).* Carpenter ants and leafminers are probably its principal insect pests. The black carpenter ant ***(Camponotus pennsylvanicus)*** commonly reduces the timber value of large trees and often makes them subject to windbreakage. The red carpenter ant *(C. **ferrugineus**)* has caused significant damage in Minnesota (2).

Leafminers are common pests of northern white-cedar. They have caused severe "scorching" of foliage and often subsequent twig, branch, or tree mortality in southeastern Canada (39). Outbreaks of the arborvitae leafminer ***(Argyresthia thuiella)*** have severely damaged white-cedar stands in Maine, and damage to ornamentals and nursery seedlings is often severe. Ornamental white-cedars are also subject to serious injury by another leafminer, *Coleotechnites thujaella (2).*

Several other insects and related organisms (such as mites) feed on northern white-cedar, but only a

few are important. The bagworm ***(Thyridopteryx ephemeraeformis),*** juniper scale ***(Carulaspis juniperi)***, and spruce spider mite ***(Oligonychus ununguis)*** can significantly damage ornamental white-cedars *(39,50)*. Heavy infestations of the Fletcher scale ***(Lecanium fletcheri)***, arborvitae aphid ***(Cinara tujafilina)***, and arborvitae weevil ***(Phyllobius intrusus)*** have occurred in nurseries *(2)*.

Northern white-cedar has few serious diseases as a forest tree, especially in immature stands; whereas in cultivation it is subject to several seedling and foliage diseases. Seedlings seem to be resistant to damping-off fungi, however. The foliage-blight fungi ***Phomopsis juniperovora*** and ***Didymascella thujina*** are among the main organisms causing seedling diseases. Beyond the seedling stage ***Phomopsis juniperovora*** blights foliage and shoots under humid conditions, and ***Didymascella thujina*** causes some unsightliness. In Quebec a snow-blight fungus ***(Phacidium*** sp.) has caused important damage in nurseries and hedges (24).

Although several root- and butt-rot fungi attack northern white-cedar, they mainly attack old or damaged trees. Because fruiting bodies of these fungi seldom appear on living trees, the most common outward sign of rot is woodpecker holes. ***Poria subacida,*** causing a white stringy butt rot, and balsam (or brown) butt rot ***(Tyromyces balsameus)*** and red-brown butt rot ***(Phaeolus schweinitzii),*** both causing cubical rots, are common in trees on knolls or other drier parts of swamps (16). Balsam butt rot can also cause extensive root rot in suppressed white-cedars *(24)*.

Winter browsing by white-tailed deer often severely damages older seedling- and sapling-stage northern white-cedar in the Lake States and can prevent the satisfactory reestablishment of the type after harvesting *(27)*, especially in deeryards. In some areas, however, damage from snowshoe hares is as great as, or greater than, from deer *(16)*.

Porcupines sometimes kill white-cedar trees or lower their growth and timber quality by feeding heavily on foliage and by girdling stems and branches. Red squirrels frequently clip branchlets with flower buds and cone clusters, and thus may significantly reduce the supply of seed available for reproduction (6). Both porcupine and squirrel damage contribute to the prevalence of stag-headedness in old trees (9).

Special Uses

The principal commercial uses of northern white-cedar are for rustic fencing and posts; other important products include cabin logs, lumber, poles, and shingles. Smaller amounts are used for paneling, piling, lagging, pails, potato barrels, tubs, ties, boats (especially canoes), tanks, novelties, and woodenware (28). Recently, white-cedar has been used for making kraft pulp and it appears excellent for particleboard. "Cedar leaf oil" is distilled from boughs and used in medicines and perfumes; boughs are also used in floral arrangements (32).

The northern white-cedar type is valuable for wildlife habitat, particularly for deer-yards during severe winters. The tree is highly preferred by white-tailed deer for both shelter and browse. Sapling stands produce a great amount of deer food (47) and clearcut stands in Michigan yielded almost 6000 kg/ha (5,340 lb/acre) of browse from tops *(16)*. White-cedar is also utilized by such mammals as the snowshoe hare, porcupine, and red squirrel. Its browse is generally rated as highly preferred by hares *(5,30)* and is sometimes heavily utilized (6). Birds common in white-cedar stands during the summer include several warblers (northern parula, black-throated green, blackburnian, black-and-white, and magnolia), white-throated sparrows, and kinglets *(9,11)*. The pileated woodpecker commonly excavates cavities in mature white-cedars to feed upon carpenter ants.

Northern white-cedar forms an attractive fringe around some lakes and peatlands. Stands with high basal area, large trees, and little undergrowth are especially attractive (35). The tree's unusual bark and foliage patterns are esthetically appealing to many forest users (27).

Northern white-cedar is widely used for ornamental plantings in the United States *(24)*, is now common in Newfoundland, and has been grown in Europe since the 16th century. White-cedar is particularly useful for barrier and shelter plantings *(29)*, and it is one of the few conifers recommended for power line rights-of-way (43).

Northern white-cedar has limited value as a watershed protector because it usually grows on gently sloping terrain. Although harvesting of white-cedar is presently on a small scale, clearcutting on peatland sites has little effect on annual water yields or water tables. Nutrient concentrations in streamflow or temperatures in trout streams should not increase significantly unless harvesting is on a massive scale *(27,35)*.

Genetics

Population Differences and Races

Northern white-cedar is morphologically similar throughout its range, with no races or varieties

reported. But a rangewide provenance study indicates that significant genetic variation does exist.

In the Lake States, provenances from intermediate latitudes generally grew best (26); in Illinois, provenances from south of the species' main range were shortest but a definite geographic pattern was lacking, perhaps because of localized ecotypes (29). In Wisconsin, upland and lowland populations less than 0.7 km (0.4 mi) apart may form separate ecotypes *(33)*, but the extent of differentiation seems to vary from one area to another.

The existence of more than 120 ornamental cultivars of northern white-cedar, which differ in foliage color and growth habit, also reflects significant genetic variation in natural populations.

Hybrids

No natural or artificial hybrids have been reported *(6,33)*.

Literature Cited

1. Ahlgren, Clifford E. 1957. Phenological observations of nineteen native tree species in northeastern Minnesota. Ecology 38:622–628.
2. Baker, Whiteford L. 1972. Eastern forest insects. U.S. Department of Agriculture, Miscellaneous Publication 1175. Washington, DC. 642 p.
3. Benzie, John W. 1963. Cutting methods in mixed conifer swamps, Upper Michigan. USDA Forest Service, Research Paper LS-4. Lake States Forest Experiment Station, St. Paul, MN. 24 p.
4. Boelter, Don H., and Gordon E. Close. 1974. Pipelines in forested wetlands: cross drainage needed to prevent timber damage. Journal of Forestry 72:561–563.
5. Bookhout, Theodore A. 1965. The snowshoe hare in Upper Michigan: its biology and feeding coactions with white-tailed deer. Michigan Department of Conservation, Research and Development Report 38. Lansing. 191 p.
6. Caulkins, Henry L., Jr. 1967. The ecology and reproduction of northern white-cedar. Thesis (M.F.), University of Michigan School of Natural Resources, Ann Arbor. 70 p.
7. Cay-ford, J. H., and R. A. Haig. 1961. Glaze damage in forest stands in southeastern Manitoba. Canada Department of Forestry, Forest Research Branch, Technical Note 102. Ottawa, ON. 16 p.
8. Crow, T. R. 1978. Biomass and production in three contiguous forests in northern Wisconsin. Ecology 59:265–273.
9. Curtis, James D. 1946. Preliminary observations on northern white cedar in Maine. Ecology 27:23–36.
10. Curtis, John T. 1959. The vegetation of Wisconsin: an ordination of plant communities. University of Wisconsin Press, Madison. 657 p.
11. Dawson, Deanna K. 1979. Bird communities associated with succession and management of lowland conifer forests. *In* Management of north central and northeastern forests for nongame birds: workshop proceedings, 1979. p. 126-131. USDA Forest Service, General Technical Report NC-51. North Central Forest Experiment Station, St. Paul, MN.
12. Dyer, Richard F. 1967. Fresh and dry weight, nutrient elements and pulping characteristics of northern white cedar, *Thuju occident&s.* Maine Agricultural Experiment Station, Technical Bulletin 27. Orono. 38 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. Foltz, Bruce W., and William F. Johnston. 1968. Gross basal area growth of northern white-cedar is independent of stand density over a wide range. USDA Forest Service, Research Note NC-61. North Central Forest Experiment Station, St. Paul, MN. 4 p.
15. Foster, A. C., M. A. Maun, and D. P. Webb. 1978. Effects of road salt on eastern white cedar *(Thuju occidentalis* L.). Canadian Forestry Service, Report O-K-277. Sault Ste. Marie, ON. 25 p.
16. Fowells, H. A., comp. 1965. Silvics of forest trees of the United States. U.S. Department of Agriculture, Agriculture Handbook 271. Washington, DC. 762 p.
17. Frank, Robert M., and Lawrence 0. Safford. 1970. Lack of viable seeds in the forest floor after clearcutting. Journal of Forestry 68:776–778.
18. Fraser, D. A. 1971. Interaction of gibberellic acid and photoperiod on reproductive and vegetative growth of white cedar seedlings *(Thuju occidentalis* L.). *In* Proceedings, Twelfth Meeting of Committee on Forest Tree Breeding in Canada, 1970. Pt. 2, p. 15-20. Canadian Forestry Service, Ottawa, ON,
19. Godman, Richard M. 1981. Personal communication. USDA Forest Service, North Central Forest Experiment Station, Rhinelander, WI.
20. Godman, Richard M., and Gilbert A. Mattson. 1976. Seed crops and regeneration problems of 19 species in northeastern Wisconsin. USDA Forest Service, Research Paper NC-123. North Central Forest Experiment Station, St. Paul, MN. 5 p.
21. Grigal, D. F., and Lewis F. Ohmann. 1975. Classification, description, and dynamics of upland plant communities within a Minnesota wilderness area. Ecological Monographs 45:389–407.
22. Heinselman, M. L. 1970. Landscape evolution, peatland types, and the environment in the Lake Agassiz Peatlands Natural Area, Minnesota. Ecological Monographs 40:235–261.
23. Heinselman, Miron L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quaternary Research 3:329–382.
24. 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.
25. Holcombe, Jeffrey W. 1976. The bryophyte flora of *Thuju* seedbed logs in a northern white-cedar swamp. Michigan Botantist 15:173–181.

26. Jeffers, Richard M. 1976. Survival and height growth of northern white-cedar from 18 provenances. *In* Proceedings, Tenth Central States Forest Tree Improvement Conference, 1976. p. 152-156. Purdue University, West Lafayette, IN.
27. Johnston, William F. 1977. Manager's handbook for northern white-cedar in the north central States. USDA Forest Service, General Technical Report NC-35 North Central Forest Experiment Station, St. Paul, MN. 18 p.
28. Johnston, William F., and Matti J. Hyvarinen. 1979. Northern white-cedar-an American wood. USDA Forest Service, FS-227. Washington, DC. 4 p.
29. Jokela, J. J., and C. L. Cyr. 1979. Performance of northern white-cedar in central Illinois. *In* Proceedings, Thirteenth Lake States Forest Tree Improvement Conference, 1977. p. 100-106. USDA Forest Service, General Technical Report NC-50. North Central Forest Experiment Station, St. Paul, MN.
30. Krefting, Laurits W. 1975. The effect of white-tailed deer and snowshoe hare browsing on trees and shrubs in northern Minnesota. University of Minnesota Agricultural Experiment Station, Technical Bulletin 302, Forestry Series 18. St. Paul. 43 p.
31. Logan, K. T. 1969. Growth of tree seedlings as affected by light intensity. IV. Black spruce, white spruce, balsam fir, and eastern white cedar. Canadian Forestry Service, Publication 1256. Ottawa, ON. 12 p.
32. Michigan State University. 1976. Proceedings, National Northern White Cedar Conference, 1975. Michigan State University Cooperative Extension Service, East Lansing. 36 p.
33. Musselman, Robert C., Donald T. Lester, and Michael S. Adams. 1975. Localized ecotypes of *Thuja occidentalis* L. in Wisconsin. Ecology 56:647–655.
34. Nienstaedt, Hans. 1981. Personal communication. USDA Forest Service, North Central Forest Experiment Station, Rhinelander, WI.
35. Ohmann, L. F., H. 0. Batzer, R. R. Buech, and others. 1978. Some harvest options and their consequences for the aspen, birch, and associated conifer forest types of the Lake States. USDA Forest Service, General Technical Report NC-48. North Central Forest Experiment Station, St. Paul, MN. 34 p.
36. Petraborg, Walter H. 1969. Regeneration of white cedar in northern swamps. Journal of Minnesota Academy of Science 36:20–22.
37. Ramsey, Guy R. 1936. Drouth susceptibility of evergreen trees in Iowa. Journal of Forestry 34:424–429.
38. Reiners, W. A. 1972. Structure and energetics of three Minnesota forests. Ecological Monographs 42:71–94.
39. Rose, A. H., and 0. H. Lindquist. 1980. Insects of eastern larch, cedar and juniper. Canadian Forestry Service, Forestry Technical Report 28. Ottawa, ON. 100 p.
40. Sakai, A. 1970. Mechanism of desiccation damage of conifers wintering in soil-frozen areas. Ecology 51:657–664.
41. Schopmeyer, C. S. 1974. *Thuja* L. Arborvitae. *In* Seeds of woody plants in the United States. C. S. Schopmeyer, tech. coord. p. 805-809. U.S. Department of Agriculture, Agriculture Handbook 450. Washington, DC.
42. Smith, P. C., and E. L. Borczon. 1981. Cutting plans for deer and timber in cedar swamps. Ontario Ministry of Natural Resources, Maple. 37 p.
43. Sorensen, R. W. 1975. Ecological and economic aspects of right of way vegetation management. Industrial Vegetation Management 7(2):2–6.
44. Stanek, W. 1977. Ontario clay belt peatlands-are they suitable for forest drainage? Canadian Journal of Forest Research 7:656–665.
45. Stoeckeler, Joseph H. 1967. Wetland road crossings: drainage problems and timber damage. USDA Forest Service, Research Note NC-27. North Central Forest Experiment Station, St. Paul, MN. 4 p.
46. Sucoff, Edward. 1975. Effect of deicing salts on woody vegetation along Minnesota roads. University of Minnesota Agricultural Experiment Station, Technical Bulletin 303, Forestry Series 20. St. Paul. 49 p.
47. Verme, Louis J. 1965. Swamp conifer deeryards in northern Michigan, their ecology and management. Journal of Forestry 63:523–529.
48. Verme, Louis J., and William F. Johnston. 1986. Regeneration of northern white cedar deeryards in upper Michigan. Journal of Wildlife Management 50: 307-313.
49. Wilde, S. A., and D. E. Spyridakis. 1967. Hydroponics as a medium for production of tree planting stock. Agronomy Journal 59:275–278.
50. Wilson, Louis F. 1977. A guide to insect injury of conifers in the Lake States. U.S. Department of Agriculture, Agriculture Handbook 501. Washington, DC. 218 p.