Cupressaceae—Cypress family

Thuja L.

arborvitae

G. J. Brand and C. S. Schopmeyer

Mr. Brand is a research forester at the USDA Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota; Dr. Schopmeyer (deceased) was technical coordinator for the previous edition of this manual.

Growth habit and occurrence. The arborvitae genus—*Thuja*—includes 2 species native to North America and 3 or 4 (depending on the authority consulted) Asian species (table 1). All individuals in the genus are aromatic, evergreen trees, but some species also have shrubby forms.

Mature northern white-cedars are medium-sized trees, usually 12 to 15 m tall and 60 to 90 cm in dbh (Harlow and others 1991). The rooting habit of mature trees is usually shallow and spreading. In addition to regeneration from seeds, vegetative reproduction by layering is common where there is sufficient moisture (Johnston 1990). Northern white-cedar grows on a wide variety of organic and mineral soils but does not develop as well on extremely wet or extremely dry sites (Johnston 1990). However, most commercial stands of northern white-cedar are in swamps. Geographical range for the species extends from Nova Scotia to Maine and westward to Manitoba and Minnesota. Isolated stands occur in west-central Manitoba, northern Ontario, southern Wisconsin, northern Illinois, Ohio, Massachusetts, Connecticut, and the Appalachian Mountains as far south as Tennessee (Little 1971).

Western redcedar can grow into large trees, especially in stream bottoms, moist flats, and gentle, north-facing slopes at low elevations (Curran and Dunsworth 1988; Schopmeyer 1974). It will grow to 45 to 60 m tall and 120 to 240 cm in dbh (Harlow and others 1991). Western redcedar develops extensive roots with a dense network of fine roots (Minore 1990). As in northern white-cedar, vegetative reproduction in western redcedar is common and provides the dominant means of regeneration in some stands. Branch layering, rooting of fallen branches, and rooting of branches attached to fallen trees have all been reported (Minore 1990). Western redcedar grows on many different soils and at a wide range of elevations. Its native range includes the Pacific Coast from northern California to southeastern Alaska; the Cascade Range in Oregon and Washington; and the Rocky Mountains in southeastern British Columbia, northeastern Washington, northern Idaho, and western Montana (Little 1971).

The 3 Asian species listed (table 1) are planted for ornamental purposes only in this country. Korean thuja reaches a height of 11 m, and Japanese thuja may grow as tall as 15 m (LHBH 1976).

Use. Both native species are valuable timber trees because their heartwood is light in weight and resists decay. The wood is used extensively for shingles, shakes, siding, and poles. Young northern white-cedar and the crowns of felled trees provide excellent browse for deer (Schopmeyer 1974). Many horticultural varieties of arborvitae with distinctive growth forms and

foliage colors are propagated vegetatively for ornamental use (Cope 1986; Dirr 1990; Rushforth 1987; Vidakovic 1991). Northern white-cedar is commonly used as a root stock for horticultural grafts of *Thuja* spp. (LHBH 1976). Extractives from western redcedar inhibit the growth of numerous bacterial and fungal species (Minore 1983).

Geographic races and hybrids. Although no naturally occurring races or hybrids of northern white-cedar or western redcedar have been reported (Kartesz 1994a; Vidakovic 1991), a hybrid between western redcedar and Japanese arborvitae has been produced (Minore 1990; Vidakovic 1991).

The many horticultural varieties of northern white-cedar and western redcedar suggest that these 2 species have considerable genetic variability. However, variation in growth and survival has not been demonstrated by all provenance tests. Northern white-cedar provenance tests demonstrated some differences in height growth rates but not consistent differences in survival rates (Jeffers 1976; Jokela and Cyr 1979). Based on their provenance work, Bower and Dunsworth (1988) concluded that western redcedar has little genetic variability. In contrast, Sakai and Weiser reported differences in frost-tolerance for western redcedar (1973).

Flowering and fruiting. Male and female flowers are borne on the same tree but usually on separate twigs or branchlets (Schopmeyer 1974). In western redcedar, flower initiation begins in spring to early summer, development ceases in the fall, pollen is shed in late winter to early spring, and fertilized cones (figure 1) are mature by fall (Owens and Molder 1984). Female flowers of western redcedar are near the tips of vigorous lateral branches and are usually higher on the tree than the male flowers. The presence of low numbers of cone buds in the dormant season indicate that a poor cone crop will follow in the fall (Owens and Molder 1984). Cones of both native and Asian species are about 8 to 12 mm long (Little 1976; Schopmeyer 1974). Western redcedar cones have 5 to 6 pairs of scales. The 3 middle pairs are fertile and contain 2 to 3 seeds (Owens and Molder 1984). Cones of northern white-cedar have 4 to 5 pairs of scales with the middle 2 or 3 pairs fertile (Briand and others 1992). Each fertile scale contains 2 seeds. During the ripening period, cones change in color from green to yellow and finally to a pale cinnamon brown (color plate). Depending on location, cones are ripe in August or September (Schopmeyer 1974). Their light chestnut-brown seeds are 3 to 5 mm long and have lateral wings about as wide as the body (figure 2). Embryos of both species have 2 cotyledons.

Collection of cones. Trees as young as 10 years old have produced cones (Curtis 1946; Edwards and Leadem 1988), but heavy cone production usually occurs only on older trees. Cones may be picked by hand from standing or recently felled trees, or the cones maybe flailed or stripped onto a sheet of canvas, burlap, or plastic. Cones of western redcedar have been harvested with aerial rakes attached to helicopters (Edwards 1986; Wallinger 1986). A good time for collection is when seeds have become firm and most of the cones have turned from yellow to brown. For northern white-cedar, the period between cone ripening and start of cone opening is only 7 to 10 days (Schopmeyer 1974). Cones of western redcedar also start to open soon after they ripen. Owens and Molder (1984) recommend collecting cones in late August to early September. Peak rate of seedfall from both species occurs about 4 to 6 weeks after the first cones have opened (Schopmeyer 1974). Mature trees of both species produce cones prolifically every 3 to 5 years, but all cones do not open at the same time. Seed release therefore progresses slowly. Substantial seed yields probably can be obtained from cones collected as late as 1 month after the first cones have opened.

Extraction, cleaning, and storage of seeds. Seeds can be extracted from cones by air-

drying for 1 to 3 weeks (VanSickle 1994) or cones may also be spread out to sun-dry. Kiln-drying is more efficient for large quantities of cones. Cones of northern white-cedar have been opened by exposing them for 4 hours in an internal-fan-type kiln at a temperature of 54 EC and a relative humidity of 38% (Schopmeyer 1974). Kiln temperatures below 43 EC are preferred, however, to prevent damage to the seeds (Schopmeyer 1974). Western redcedar cones were opened in 24 to 36 hours at a temperature of 33 EC (Edwards 1986), 18 to 20 hours at 41 EC (Owens and Molder 1984), or 27 EC for 12 hours (Henchell 1994). Higher temperatures increase the probability that seeds will be damaged. After cones have opened, seeds are extracted in a mechanical cone shaker or tumbler and separated from the cone scales by fanning or gravity separation. Seeds should not be dewinged (Edwards and Leadem 1988; Gordon and others 1991).

The number of fully developed seeds in each cone can vary dramatically. As few as 2 to as many as 12 (average 7.7) fully developed seeds were counted in northern white-cedar cones (Briand and others 1992). For western redcedar, cones from natural stands contained an average of 2.6 filled seeds/cone, whereas cones from seed orchards contained an average of 6 fully developed seeds per cone (Colangeli and Owens 1990). One kilogram of cleaned northern white-cedar seeds contains an average of 763,000 seeds (346,000/lb) (Schopmeyer 1974). The average number of cleaned western redcedar seeds reported is 913,000/kg (414,000/lb) (Schopmeyer 1974). Empty seeds can be readily separated from full seeds in a seed aspirator or blower.

Arborvitae seeds are orthodox in storage behavior. Seeds should be stored in fiber containers with plastic or foil liners (Gordon and others 1991). Seeds stored at a moisture content of 5 to 10% in sealed containers at 0 to 5 EC should remain viable for up to 5 years (Gordon and others 1991). For longer periods, storage at !18 EC is recommended.

Pregermination treatments. The need for stratification to ensure that a high percentage of seeds germinate uniformly is not clear. Some authors state that stratification is not needed. Others recommend stratification for 30 to 60 days in moist medium at 1 to 5 EC (Henchell 1994; Schopmeyer 1974). Dirr and Heuser (1987) report that 2 weeks of stratification will improve germination of Japanese thuja. Germination of northern white-cedar and western redcedar seeds is tested by placing seeds on top of moist germination paper kept at 20 to 30 EC; no pretreatment is recommended. Germination is epigeal (figure 3). The first count of germinated seeds is made after 7 days and the last count after 21 days (ISTA 1993).

Nursery practice and seedling care. Northern white-cedar and western redcedar seedlings are not produced in large numbers but can be grown in both bareroot nursery beds and in containers. Many ornamental varieties of arborvitae, both native and Asian, are propagated from cuttings or by layering (Dirr and Heuser 1987). Cultural practices vary by nursery.

The irregular shape and small size of western redcedar seeds make it difficult to sow the seeds mechanically. Coating seeds with fine-textured materials such as clay, sand, charcoal, or peat has been attempted to make the seeds more uniform in size and shape (Edwards and Leadem 1988). This process should be done soon before sowing, because seed viability is reduced if seeds are stored after being coated (Edwards and Leadem 1988).

In bareroot nurseries, seedlings are grown as 1+1, 2+0, 2+1, and 3+0 stock. Fall-sowing is preferred for northern white-cedar and spring-sowing for western redcedar. Some nurseries soak seeds in water for 24 to 48 hours and then stratify them for 7 to 60 days at 2 EC before sowing. Because of better mycorrhizal colonization, planting western redcedar seeds in nurserybeds that have not been fumigated for 1 year seems beneficial (Henchell 1994). Average seedbed density for western redcedar is about 500 seedlings/m^2 (46/ft^2) but varies from 240 to

1000/m^2 (22 to 93/ft^2) (Edwards and Leadem 1988; Henchell 1994). The wider spacings may produce higher quality seedlings (van den Driessche 1984). Sowing depth varies from 0.3 to 1.0 cm (⅛ to ⅜ in) (Schopmeyer 1974). In another approach used in Minnesota, VanSickle (1994) sowed northern white-cedar seeds at 0.15 cm (1/16 in) and covered them with a double layer of hydromulch. Western redcedar seeds have also been sown on the surface, pressed into the soil by the packing roller of a seed drill, and covered immediately with shade material (Henchell 1994). First-year northern white-cedar seedlings are grown both with half-shade (Jones 1994) and without shading (VanSickle 1994). Shading (50 to 70%) is recommended for first-year western redcedar seedlings. Soil moisture needs to be monitored closely because seed and seedlings of western redcedar are sensitive to drying (Henchell 1994).

Container seedlings have become more common in the last decade and can be produced in 1 or 2 years. Various container sizes are used, depending on the desired size of the outplanted stock. Common container volumes used are 66 to 164 ml (4 to 10 in^3) (Olson 1994; Schaefer 1994). Seedlings of northern white-cedar grown from fall-planted seeds are ready for outplanting in May, unless the larger containers are used. Seedlings of western redcedar grown from spring-planted seeds are ready for outplanting in the fall or following spring. Seedlings in larger containers are grown in the greenhouse for 10 to 18 months before outplanting. Seeds sown in the containers are covered with a thin layer (about 0.3 cm, or ⅛ in) of crushed granite (Olson 1994) or quartz (Schaefer 1994). Western redcedar seedlings grown in containers and chemically root pruned by painting the inside of the container with latex paint containing copper carbonate showed good height and volume growth when outplanted (Curran and Dunsworth 1988). In container-grown wester redcedar, a mild nitrogen and moisture stress after the seedlings reach 8 to 10 cm (3 to 4 in) produces hardened stock with a balanced root to shoot ratio (Schaefer 1994). Seedlings grown for 1 year in containers and then transplanted to the nursery bed (plug+1 transplants) are well-balanced and have been successful when outplanted (Ramirez 1993).

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Figure 1—*Thuja plicata,* western redcedar: cone, H 6.

Figure 2—*Thuja occidentalis,* northern white-cedar: exterior view of seed, longitudinal section with labels, and transverse section showing 2 cotyledons; all at H 6.

Figure 3—*Thuja occidentalis,* northern white-cedar: seedling development at 1, 5, and 25 days after germination.

Table 1—*Thuja,* arborvitae: nomenclature

Scientific name & synonym(s)	Common names	Occurrence
***T. occidentalis* L.** *T. obtusa* Moench *T. odorata* Marshall	**northern white-cedar,** white-cedar, eastern arborvitae, swamp-cedar arborvitae, eastern white-cedar	Nova Scotia to Maine & W to Minnesota & Manitoba: S in Illinois, Ohio, & New York; locally in Appalachian Mtns.
***T. plicata* Donn ex D. Don** *T. plicata* D. Don; *T. plicata* Donn *T. plicata* Donn ex D. Don in Lamb. *T. gigantea* Nutt. *T. menziesii* Dougl. ex Endl. *T. lobbii* Hort. ex Gord.	**western redcedar,** Pacific redcedar, giant-cedar, arborvitae, giant arborvitae, canoe-cedar, shinglewood	Pacific Coast region, from SE Alaska to N California, Cascade Mtns. in Washington & Oregon, Rocky Mtns in British Columbia, N Idaho, & W Montana
***T. standishii* (Gord.) Carr.** *T. japonica* Maxim. *Thujopsis standishii* Gord.	**Japanese thuja,** Japanese arborvitae	Japan
***T. koraiensis* Nakai** *T. kongoënsis* Nakai	**Korean thuja,** Korean arborvitae	Korea
***T. sutchuensis* Frachet**	**Sichuan thuja**	China

Sources: Cope (1986), Kartesz (1994a, b), Little (1979), Rushforth (1987), Vidakovic (1991).