Tamaricaceae—Tamarix family

Tamarix chinensis Lour.

saltcedar or five-stamen tamarisk

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Synonym. *T. pentrandra* Pall.

Growth habit, occurrence, and use. Saltcedar (*Tamarix chinensis* (Lour.)) and smallflower tamarisk (*T. parviflora* DC.) hybridize in the Southwest (Baum 1967; Horton and Campbell 1974) and are deciduous, pentamerous tamarisks that are both commonly referred to as saltcedar. Saltcedar is a native of Eurasia that has naturalized in the southwestern United States within the last century. It was introduced into the eastern United States in the 1820s (Horton 1964) and was once widely cultivated as an ornamental, chiefly because of its showy flowers and fine, graceful foliage. However, saltcedar has been an aggressive invader of riparian ecosystems in the Southwest (Reynolds and Alexander 1974) and is the subject of aggressive eradication campaigns. It achieves heights of 12 m and trunk diameters of 0.5 m in southern New Mexico and trans-Pecos Texas (Everitt 1980). Although considered a threat to native vegetation, saltcedar has been utilized for browse, firewood, and lumber and also to produce premium honey (Everitt 1980). Saltcedar is halophytic and tolerates an extreme range of environments from below sea level to above 2,100 m (Everitt 1980). Though a riparian plant, it is also drought tolerant and can survive indefinitely in non-saturated soils, making it a "facultative phreatophyte" (Turner 1947). In some areas, saltcedar thickets are valued nesting habitat for white-winged doves (Reynolds and Alexander 1974). Saltcedar can naturally reproduce vegetatively from roots and can layer when foliage is buried by sediment (Everitt 1980). These prodigious reproductive capabilities are well suited to colonizing riverbanks and disturbed areas (Horton and others 1960). Because saltcedar is a heavy water user, its spreads rapidly along drainages and flood plains—for example, the infested area increased from 4,000 to 364,000 ha in 41 years (1920 to 1961), (Robinson 1965)—and has required extensive eradication or control efforts.

Flowering and fruiting. The pink to white flowers, borne in terminal panicles, bloom from March through September. A succession of small capsular fruits ripen and split open during the period from late April through October in Arizona (Horton and others 1960). Seeds are minute and have an apical tuft of hairs (figures 1 and 2) that facilitates dissemination by wind. Large numbers of small short-lived seeds are produced that can germinate while floating on water, or within 24 hours after wetting (Everitt 1980).

Collection, extraction, and storage. Fruits can be collected by hand in the spring, summer, or early fall. It is not practical to extract the seeds from the small fruits. At least half of the seeds in a lot still retained their viability after 95 weeks in storage at 4.4 °C, but seeds stored at room temperature retained their viability for only a short time (Horton and others 1960).

Figure 1—*Tamarix chinensis*, saltcedar: longitudinal section through a seed.

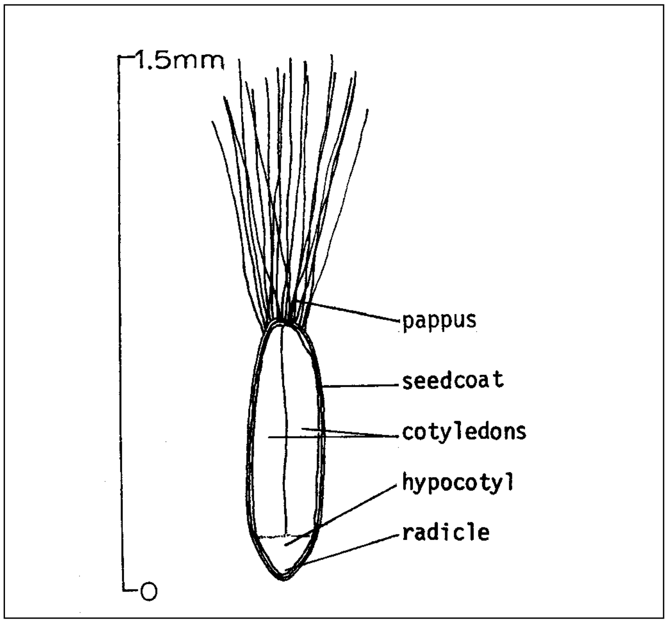
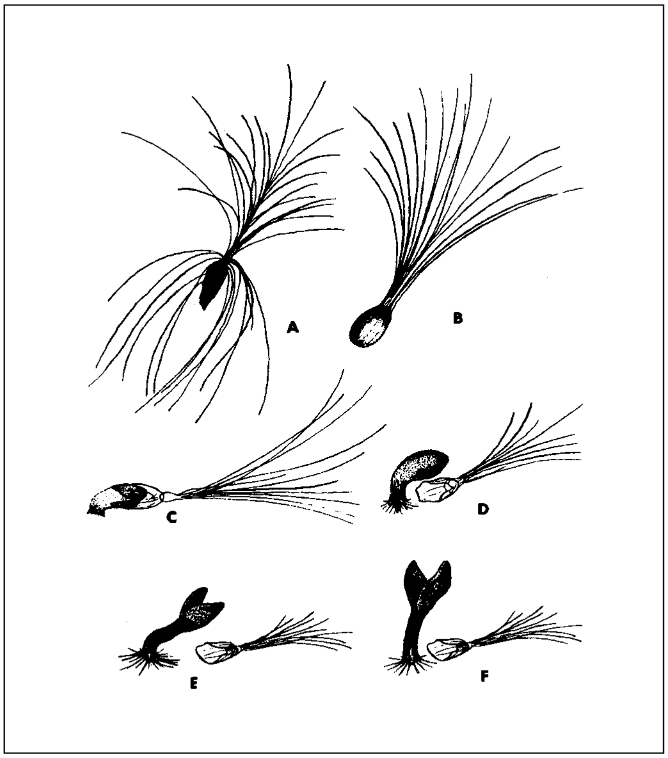


Figure 2—*Tamarix chinensis*, saltcedar: dry seed (**A**) and seedling development at the following intervals after moistening the seed—several hours (**B**), 8 hours (**C**), 24 hours (**D**), 40 hours (**E**), 48 hours (**F**) (drawings by Dennis C. Jackson, from Horton and others 1960).



Germination tests. Fresh seeds usually germinate within 24 hours after imbibing water (figure 2). No pretreatment is necessary. Germination tests have been run in moist soil in covered petri dishes at room temperature. The germination rate after 24 hours averaged 78% and the percentage germination after 6 days was 88% (Horton and others 1960). Seed can survive up to a year in cold storage (Merkel and Hopkins 1957).

Nursery practice. Germination and survival is favored by fine-grain sediment. Bare, sunny, saturated soil is ideal for the first 2 to 4 weeks of life, but survival is limited because of slow early seedling growth (Everitt 1980). Top height averages about 2.5 cm (1.0 in) 30 days after emergence, and seedlings average only 10 cm (4 in) tall after 60 days. At this time, roots are about 15 cm (6 in) long. Soil must be kept continuously moist during this establishment period; 1 day of drought can kill most seedlings (Reynolds and Alexander 1974).

Saltcedar is also readily propagated from cuttings. Cuttings will root during any season, if planted in moist soil at 16 °C (Gary and Horton 1965). Hardwood cuttings should be at least 2 cm ($^3/_4$ in) thick. A peat and perlite medium under mist works well with softwood cuttings, but root systems may be sparse and difficult to handle (Dirr and Heuser 1987). Seedlings are hearty after they become established and can withstand severe drought (Horton and others 1960). Softwood cuttings should be weaned from mist as soon as rooting begins to avoid decline from excessive moisture (Dirr and Heuser 1987).

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Taxodiaceae—Redwood family

Taxodium L.C. Rich.

baldcypress

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Growth habit, occurrence, and use. Baldcypresses are large deciduous conifers that occur naturally in wetlands of the Southeastern and Gulf Coastal Plains. Two species, once classified as varieties of a single species, are now recognized (table 1). The ranges of these species overlap in the Southeast and Gulf South; baldcypress extends much further north and west, however. They are often difficult to identify where mixed (Wilhite and Toliver 1990). Baldcypress may be encountered in almost all temperate regions of the world, as it has been planted extensively as an ornamental. It was introduced in Europe as early as 1640 (Bonner 1974). Baldcypress wood is well-known for its use in boat construction, pilings, interior trim, flooring, paneling, and many other items. It is an important source of wildlife food and habitat and a valuable component of wetland hydrology (Wilhite and Toliver 1990).

Flowering and fruiting. The monoecious flowers of baldcypress appear in March to April, before the leaves. The male catkins are about 2 mm in diameter and are borne at the end of the previous year's growth in slender, purplish, tassel-like clusters 7 to 13 cm long. Female conelets are found singly or in clusters of 2 or 3 in leaf axils near the ends of the branchlets (Vines 1960; Wilhite and Toliver 1990). The globose cones turn from green to brownish purple as they mature in October to December. Flowering and fruiting of pondcypress is essentially the same as for bald-

Figure 1—*Taxodium, baldcypress*: cones of *T. distichum*, baldcypress (**top**) and *T. ascendens*, pondcypress (**bottom**).

cypress (Wilhite and Toliver 1990). Baldcypress cones are 13 to 36 mm in diameter (figure 1), and consist of a few 4-sided scales that break away irregularly after maturity. Each scale bears 2 irregularly shaped seeds that have thick, horny, warty

Table 1—*Taxodium,* baldcypress: nomenclature and occurrence

Scientific name & synonym(s)	Common name(s)	Occurrence
T. ascendens **Brongn.** *T. distichum* var. *imbricarium* (Nutt.) Croom *T. distichum* var. *nutans* (Ait.) Sweet	**pondcypress**, pond baldcypress, cypress	Coastal plain from Virginia to Florida & Louisiana
T. distichum **(L.) Rich.**	**baldcypress,** common bald cypress, gulf cypress, red cypress, tidewater red cypress, white cypress, yellow cypress, cypress	Coastal plain from Delaware & Florida W to Texas & N to Illinois in Mississippi River Valley; planted from Michigan to Massachusetts

Sources: Little (1979), Wilhite and Toliver (1990).

coats and projecting flanges (figures 2 and 3). Collections from 45 families of baldcypress from Mississippi to Texas found that cones contained anywhere from 2 to 34 seeds, with an average of 16 (Faulkner and Toliver 1983). The proportion of seeds with embryos is frequently less than 50%, however. Some seeds are borne every year, and good crops occur at 3- to 5-year intervals.

Figure 2—*Taxodium*, baldcypress: seeds of *T. distichum*, baldcypress (**top**) and *T. ascendens*, pondcypress (**bottom**).

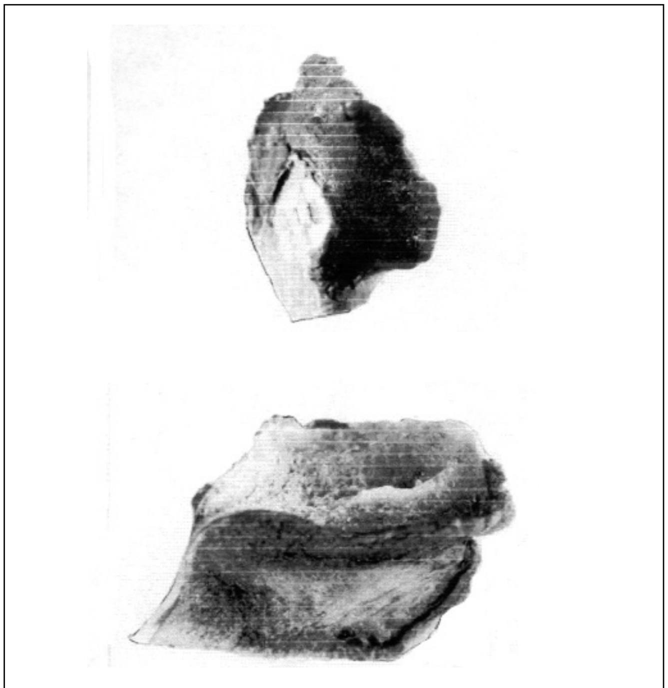
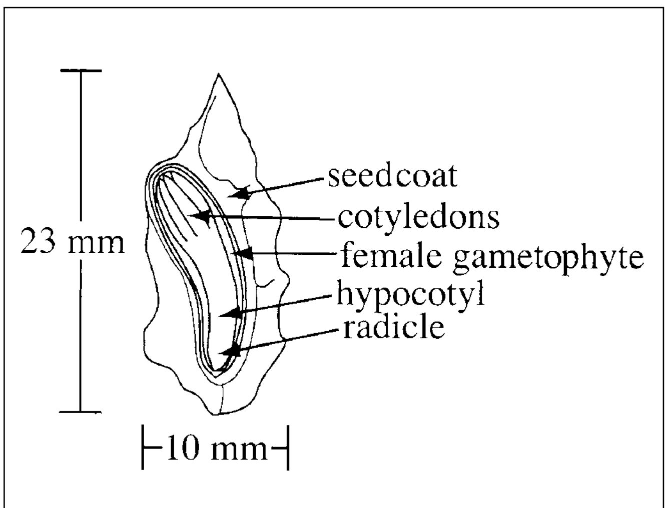


Figure 3—*Taxodium distichum*, baldcypress: longitudinal section through a seed.



Two insect pests destroy significant amounts of baldcypress and pondcypress seeds—southern pine coneworm (*Dioryctria amatella* (Hulst)) and baldcypress coneworm (*D. pygmaeella* Ragonot). The baldcypress seed midge (*Taxodiomyia cupressi* Schweinitz) forms small round galls inside the cones of baldcypress (Hedlin and others 1980; Merkel 1984). The seed midge apparently does little damage to seeds, but the galls are difficult to separate from the seeds and become a quarantine problem for seed exporters.

Collection, extraction, and storage. Mature, dry cones can be picked by hand from standing or felled trees and spread in a thin layer for air-drying. The dried cones should be broken apart by flailing or dry maceration. The resin in the cones presents a major problem in separation and cleaning because it causes seeds and cone fragments to stick together. The resin also gums up mechanical macerators. One possible solution is to place the dried seeds and cone fragments in a freezer to harden the resin, then run them through a macerator again while the resin is still in a solid state. Resin can be cleaned from equipment with alcohol or other organic solvents.

The number of seeds per cone volume for baldcypress averages about 58 kg/hl (45 lb/bu) of fresh cones. About 50 kg of seeds can be obtained from 100 kg (110 lb/220 lb) of fresh cones, and there are 7,300 to 10,000 cones/hl (2,600 to 3,550 cones/bu) (Bonner 1974). For baldcypress, the average number of cleaned seeds per weight determined from 26 samples was 11,500/kg (5,200/lb) with a range of 5,600 to 18,500/kb (2,540 to 8,400/lb). One sample of pondcypress from Florida contained about 9,000 seeds/kg 4,100 seeds/lb) (Bonner 1974). Baldcypress seeds keep well in dry storage at 2 to 5 °C for at least 3 years. Because they appear to be orthodox in storage behavior, longer storage under the same conditions will probably succeed.

Germination. Baldcypress seeds exhibit a moderate amount of dormancy that can be overcome by cold stratification (table 2). For germination testing, moist stratification for 30 days at 3 to 5 °C is recommended, followed by 28 days of testing at alternating temperatures of 20 °C for 16 hours (dark) and 30 °C for 8 hours (light) (ISTA 1993). Studies with collections from the Gulf Coast region suggested that dormancy in both species is regulated by the seedcoat, and any treatment that softens or weakens the coats will increase rate of germination. Soaking for 4 hours in concentrated sulfuric acid was recommended as the easiest treatment (Murphy and Stanley 1975). An alternative method for nursery use has been to soak the seeds in water at 4 °C for 90 days or until ready to plant in the spring. Pondcypress seeds respond well to 60 to 90 days of stratification at 4 °C in peat moss, preceded by a 24- to 48-hour soak in 0.01% citric acid (Bonner 1974). In addition to the test conditions recommended in table 2, tetrazolium staining can be used to determine viability (ISTA 1993).

Nursery practice. Spring-sowing of pretreated seeds and fall-sowing (December) of untreated seeds are both practiced. The latter method has proved successful in northern nurseries. Seeds and cone scales can be broadcast or drilled together and should be covered 6 to 12 mm ($^1/_2$ to $^3/_4$ in) deep with sand, soil, or peat moss. Beds should then be mulched with leaves or other material, especially when fall sowing is used. Shade may be needed in the South from June to September, and beds must always be well watered. The resinous seeds are not eaten to any extent by rodents or birds (Bonner 1974). Germination is epigeal (figure 4). Rooting of cuttings is difficult but possible, as is grafting (Dirr and Heuser 1987).

Figure 4—*Taxodium distichum*, baldcypress: seedling development at 3 and 8 days after germination.

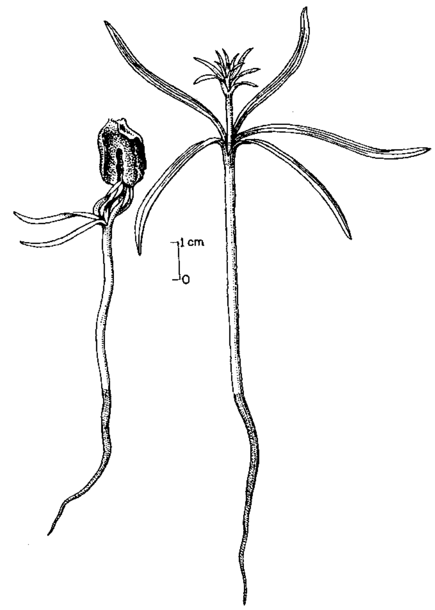


Table 2—*Taxodium,* baldcypress: germination test conditions and results on stratified seedlots

	Germination test conditions				Germinative energy		Germinitive capacity		
	Daily		Temp (°C)						
Species	light (hr)	Medium	Day	Night	Days	(%)	Days	(%)	Samples
T. ascendens	8	Kimpak	30	20	30	76	8	93	4
T. distichum	8	Kimpak	30	20	30	67	17	74	7

Sources: Bonner (1974), ISTA (1996).
Germ = germinitive; percentages are based on full seeds only.

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Taxaceae—Yew family

Taxus L.

yew

Nan C. Vance and Paul O. Rudolf

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Growth habit. The yews—members of the genus *Taxus* of the family Taxaceae—are non-resinous evergreen gymnosperms that are widely distributed throughout the moderate zone of the Northern Hemisphere (table 1). They grow primarily in the understory of moist, forested habitats in cool, temperate to subtropical climates (Price 1990). The growth form may be a tree or a shrub. In the understory, the yew's sprawling branchiness and spreading crown enable it to capture light gaps in the canopy. The tree may convert to shrub form if the main shoot is injured or declines and is replaced by lateral branches or new growth. Shrubbiness may also be sustained by frequent browsing. Crowns of these shrubby forms may attain as much as 24 m in diameter (Bugala 1978). The main stem of the yew tree can become quite stout in proportion to its height. Often the large diameter is attained by multiple stems that have fused over time. English yew has reached great age (1,000+ years) and girth, especially those planted in country churchyards (Lewington and Parker 1999).

Cultivated for centuries, the many English yew cultivars show distinct morphological differences in growth form and habit and in needle form and color (Krüssmann 1983). Since the 1920s, cultivars of *T.* × *media* Rehder (a hybrid of English and Japanese yews) have increased the number and variety of these commercially important ornamental shrubs (Chadwick and Keen 1976). The height of most yew species ranges from 6 to 12 m, although open-grown English yew may reach heights of 12 to 25 m and grow extremely thick trunks up to 17 m in girth (Krüssmann 1983; Lewington and Parker 1999). Florida yew is a small, broad tree, about 1 to 5 m in height at maturity (Redmond 1984). Pacific yew trees growing in the wild may reach diameters as large as 6 m and heights up to 18 m under favorable conditions (Bolsinger and Jaramillo 1990). A shrubby form of the

Table 1—*Taxus,* yew: nomenclature and occurrence

Scientific name & synonym(s)	Common name	Occurrence
***T. baccata* L.** *T. baccata* ssp. *eubaccata* Pilger.	**English yew,** common yew	Throughout Europe & Algeria, N Iran & the Himalayas
***T. brevifolia* Nutt.** *T. baccata* ssp. *brevifolia* Pilger.	**Pacific yew**	From SE Alaska S to N California & central Nevada; E to coastal Oregon & Washington to W Montana
***T. canadensis* Marsh.** *T. baccata* ssp. *canadensis* Pilger.	**Canada yew,** eastern yew, ground hemlock	E from Ontario into E Canada, S to Virginia & Tennessee
***T. chinensis* (Pilger.) Rehder** *T. celebica* (Warburg) Li. *T. mairei* S.Y. Hu ex Liu. *T. yunnanensis* Cheng & L.K.Fu.	**Chinese yew,** Maire yew, Yunnan yew	Central & W China from Yunnan to Guangxi
***T. cuspidata* Sieb. & Zucc.** *T. baccata* ssp. *cuspidata* Pilger.	**Japanese yew**	Throughout Japan & in E China
***T. floridana* Nutt. ex Chapman** *T. baccata* ssp. *floridana* Pilger.	**Florida yew**	Along Appalachicola River bluffs in N Florida
***T. globosa* Schltdl.** *T. baccata* ssp. *globosa* Pilger.	**Honduran yew,** Guatemalan yew, Mexican yew	From NE Mexico to Guatemala & El Salvador
***T. wallichiana* Zucc.** *T. baccata* ssp. *wallichiana* Pilger.	**Himalayan yew**	Himalayan Mtns from E Afghanistan & N India, E to Tibet, Burma & the Philippines

Sources: Krüssmann (1983), Rehder (1971), Rudolf (1974), Voliotis (1986).

Pacific yew is common east of the Cascade Divide (Arno and Hammerly 1977).

Occurrence. Eight of the recognized species of yews grow in the United States (Krüssmann 1983; Rehder 1951) (table1). English, Japanese, and Himalayan yews occur in Europe and Asia (Bugala 1978; Voliotis 1986) and Honduran, Florida, Canada, and Pacific yews occur in North America (Little 1971) (table 1). Chinese yew, considered a separate species in Chinese flora, is found in the mountainous regions of China up to about 3,000 m (Lee 1973; Zhang and Jia 1991). *Taxus mairei* (Lemee et Level.) S.Y. Hu & Liu; *T. yunnanensis* Cheng and L.K. Fu; and *T. celebica* (Warburg) Li may also be identified as sub-species or varieties of *T. chinensis* (Krüssmann 1983). Species classification within the genus is disputed and its phylogeny is not well understood (Bugala 1978; Voliotis 1986).

Of the 4 species native to the North American continent, 3 of them—Pacific, Canada, and Florida yews—occur in the United States. Honduran yew ranges from Honduras to southern Mexico. Of the species growing in the United States, Pacific yew has the most widespread range (table 1), and Florida yew, which is confined to the Appalachicola River bluffs in northwest Florida, the most restricted. Although distinct geographic races have not been fully established, allozyme evaluation of 54 Pacific yew populations from 174 geographic areas indicate that Sierra Nevada populations were genetically distinct from Idaho, Montana, and northeast Oregon populations (Doede and others 1993). Six geographic seed zones established by the Oregon State Department of Forestry divide Oregon into north coast, south coast, Willamette valley, south valley, north Cascades, south Cascades; and an elevation band in the Cascades separated at 762 m (Randall 1996).

Use. *Taxus* is the only genus of the yew family of economic importance (Price 1990). For centuries, indigenous people have used yew species in traditional utensils and medicines (Hartzell 1991). North American indigenous people used yew for implements, including bows and dip-net and drum frames, as well as for medicines (Alaback and others 1994). In Europe and Asia, the wood of the tree was once prized for making bows and is still valued for its quality in making fine musical instruments, cabinets, and utensils (Ambasta 1986; Hartzell 1991). Yew has gained additional importance in recent years for a unique class of diterpenoid alkaloids, or taxanes, contained in its needles, bark and seeds (Miller 1980). These taxanes are the source of a chemotherapeutic drug (taxol) used to treat cancer (Rowinsky and others 1990). The fruit-like arils are eaten by birds, and birds and small mammals eat the seeds. Although rabbits (*Sylvilagus* spp.), deer (*Odocoileus* spp.), and elk (*Cervus elaphus*) feed on foliage, leaves, and shoots of the Pacific yew, the European yew is reportedly toxic to horses and cattle but apparently not to white-tailed deer (*O. virginianus*) (Nisley 2002; Smith 1989; Veatch and others 1988).

Flowering and fruiting. Almost all yew species are dioecious; however, Canada yew is monoecious. Nevertheless, a small percentage of unisexual plants have been observed in this species (Allison 1991). Co-sexuality has been reported in Pacific yew—fruits and seeds have been observed on branches of male trees (DiFazio and others 1996; Owens and Simpson 1986). Co-sexuality and sex reversion have also been reported in other taxa (Chadwick and Keen 1976).

Yew flowers are small and solitary and arise from axillary buds. Female buds consist of single ovules surrounded by bracts. Anthesis is indicated by the appearance of the micropylar opening in the exposed ovule, which eventually develops into a seed. Male buds usually cluster along the underside of the previous season's branches. The male flower at anthesis is a stalked, globose head on which are 14 stamens, each with 5 to 9 microsporangia or pollen sacs. The pollen is shed between February and May (table 2). Dry pollen grains are yellow, indented spheroids, lacking sacci; diameters range from 19 to 26 µm (Owens and Simpson 1986).

The fruit, which ripens from late summer through autumn, consists of a scarlet fleshy, cup-like aril (figure 1)

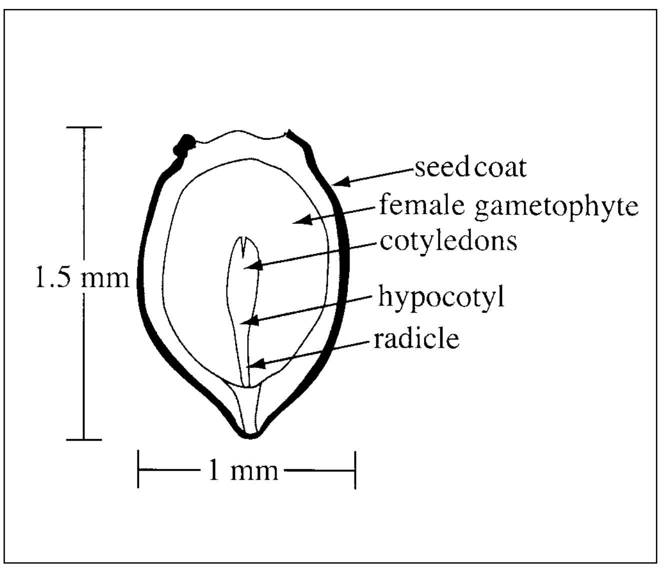
Figure 1—*Taxus canadensis*, Canada yew: fruits.

bearing a single, hard, ovate seed up to 6 mm long (figures 2 and 3). The mature seed has a greenish brown to brown seedcoat and is filled with white megagametaphyte tissue (rich in lipids) that surrounds a small embryo 1 to 2 mm long. Times of flowering, fruit ripening, and seed dispersal for each species are listed in table 2.

Little information is available on the frequency of good seedcrops among the yews, but most species produce some seeds almost every year (Chadwick and Keen 1976; Harlow and Harrar 1958). Flowering and seed production was found for Pacific yew in western Oregon to be related to overstory openness and tree vigor (DiFazio and others 1997; Pilz 1996a). However, predation of fruit on trees in the open was higher, limiting seed production (DiFazio and others 1998). For Japanese yew, good crops are reported every 6 to 7 years (Rudolf 1974). English yew begins to produce seeds at about 30 years of age (Dallimore and Jackson 1967).

Figure 2—*Taxus*, yew: seeds of *T. baccata*, English yew (**left**); *T. brevifolia*, Pacific yew (**middle**); *T. canadensis*, Canada yew (**right**).

Figure 3—*Taxus canadensis*, Canada yew: longitudinal section through a seed.



Comparable information for the other species is lacking. For dioecious species, good seedcrops are produced where there is a good intermixture of male and female trees. Pollen may limit seed production in some populations of Canada yew where deer browsing has created widely spaced plants that produce little pollen (Allison 1990). Although pollination was found to be limiting, it was not the primary factor limiting seed production in Pacific yew trees examined in western Oregon (DiFazio and others 1998). Yew seeds have been found to survive in a soil seedbank for several years (Minore and others 1996). Although seeds will germinate under mature overstories in canopy gaps, seedlings may be abundant following disturbance such as burning and overstory removal. However, Crawford (1983) noted that, in Idaho, most abundant yew seedlings were found growing in forest litter and decaying wood.

Collection of fruits. The maturation of seeds and ripening of arils (full expansion and orange-red coloration) may occur over a span of months. Over this time, losses to birds and small mammals such as chipmunks (*Eutamia*s spp.) can be considerable (DiFazio 1995). To prevent losses to predation, yew fruits should be picked frequently from the branches, beginning when individual fruits first ripen. To ensure that adequate amounts of seeds are collected in specific seed collection areas, bagging branches of desirable trees well before fruit ripens is recommended so that fruits are not lost or destroyed by squirrels (*Citellus* spp.) and other predators (DiFazio and others 1998). If returning repeatedly to individual trees is impractical, harvesters can bag branches in July with light-weight mesh bags and then collect the fruits in late fall.

Randall (1996), when collecting seeds in Oregon and Washington, noted differences in phenology in nursery-grown yews from seeds collected in the coastal range and the Cascades. Seed zones that have been identified should be used for collecting; ideally seeds should be collected from the approximate area where the yew trees will be grown.

Extraction and cleaning. Seeds should be extracted from the fruit shortly after harvest (storage with fruit promotes mold) by macerating the fleshy arils in water. A blender with the blades covered by rubber tubing (Munson 1986) and set at low speed will efficiently and quickly separate seeds from arils without damaging seeds. Light, unfilled seeds float to the top and can be easily removed. In some species, the membranous outer seedcoat is partially destroyed during extraction; in others, it remains tightly fixed to the bony inner coat. After extraction, excess moisture should be dried from seeds. Seeds can then be weighed, sown, cold-stored, or stratified as soon as possible. The number of cleaned seeds per weight is listed in table 3. Purity of seedlots generally ranges from 96 to 100%, and soundness, from 78 to 99% (Rudolf 1974).

Storage. Yew seeds are orthodox in storage characteristics and, if kept at low moisture content, may be successfully stored frozen for years without losing viability. The viability of yew seeds can be maintained for 5 or 6 years if they are dried just after extraction at room temperature for 1 or 2 weeks and then stored in sealed containers at 1 to 2 °C (Heit 1967). If seeds are dried to 15 to 25% relative humidity (moisture content of 2 to 3%), seedlot viability of greater than 90% can be maintained for weeks at 25 °C. Pacific yew seeds have a high lipid content (mega gametophyte lipid content is about 71% of the dry mass); therefore, long-term storage conditions should maintain seeds at 14% relative humidity and subzero temperatures (Walters-Vertucci and others 1996). Analysis of seeds for cryopreservation indicates that they can be stored at –18 to –20 °C without losing viability, provided that they have reached sufficient maturity, and that they probably will remain viable for decades under these conditions (Walters-Vertucci and others 1996). Yew seeds can be held for several months in cold stratification without losing viability. Reasonably good viability of English yew seeds was maintained for up to 4 years by storing them in moist sand or acid peat at low temperatures (Rudolf 1974).

Pregermination treatments. Yew seeds are slow to germinate; natural germination usually does not take place until the second spring after seedfall (Suszka 1978). Viable seeds of Pacific yew have been found in soil seedbanks for several years (Minore 1994). Although a variety of birds and small mammals eat, digest, and disperse yew seeds (Bartkowiak 1978), germination does not appear to be hastened by their passing through the alimentary canal of birds. Yew seeds have a strong but variable dormancy that can be broken by warm-plus-cold stratification (Suszka 1978). One recommendation is to hold the seeds for 150 to 210 days at 16 to 18 °C, then for 60 to 120 days at 2 to 5 °C (Heit 1967, 1969). The ISTA rules specify prechilling yew seeds for 270 days at 3 to 5 °C. Steinfeld (1993a) reported on 2 groups of seeds collected in the fall in Oregon that were stratified during the fall and winter. One group was chilled for 1 month and the other was kept at warm temperatures for 5 months and then chilled for 2 months. The seeds were sown in bare-root beds covered with mulch the following spring.

Table 2—*Taxus*, yew: phenology of flowering and fruiting

Species	Location	Flowering	Fruit & seed ripening	Seed dispersal
T. baccata	W Europe	Mar–May	Aug–Oct	Aug–Oct
T. brevifolia	Washington & Oregon	Mar–May	July–Oct	July–Oct
T. canadensis	Minnesota & Wisconsin	Apr	Aug–Sept	Aug–Sept
T. cuspidata	Japan	Apr–June	Sept–Oct	Oct
T. floridana	NW Florida	Jan–Mar	Aug–Oct	Aug–Oct

Sources: Allison (1990), Chadwick and Keen (1976), Redmond (1984).

Table 3—*Taxus*, yew: seed yield data

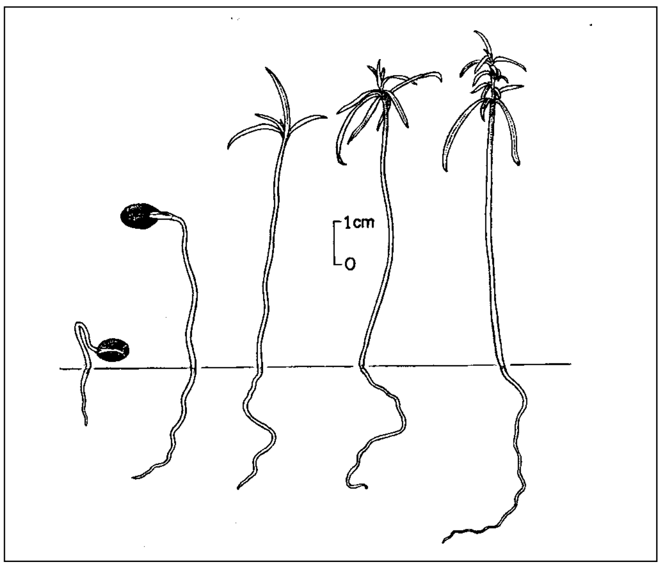
		Cleaned seeds/weight				
		Range		Average		
Species	Place collected	/kg	/lb	/kg	/lb	Samples
T. baccata	Western Europe	13,900–18,000	6,300–8,200	17,000	7,700	14
	NE US	13,200–15,000	6,000–6,800	14,100	6,400	3
T. brevifolia	Carson & Skamania Cos., Washington	32,400–36,200	14,700–16,500	33,100	15,000	2
	S Cascades, Oregon	23,800–25,900	10,800–11,800	24,950	11,300	10
	Central Cascades, Oregon	26,330–39,950	12,000–18,200	31,077	14,100	4
T. canadensis	Upper mid-West	33,000–62,400	15,000–28,400	46,300	21,000	4
	Minnesota & Wisconsin	35,700–38,460	16,200–17,500	37,000	16,800	
T. cuspidata	Japan	24,700–43,000	11,200–19,500	31,300	14,200	7
	NE US	14,840–19,300	6,700–8,800	16,300	7,400	3

Sources: Allison (1995), Heit (1969), Rudolf (1974), Vance (1993), Yatoh (1957).

Germination was negligible for the cold-treated seeds and about 5% for the warm/cold-treated seeds; however, in the following spring, the germination rate of the remaining seeds combined with that of the previous spring exceeded 95%. No difference in total germination between the 2 treatment groups was detected by the second year.

Germination and seed viability tests. Germination of yew seeds is epigeal (figure 4). Because of the deep dormancy of the seeds, germination will be sporadic over the course of several years. Germination percentages after the first year do not indicate the potential of the seeds to germinate, for germination will continue in the following year (Heit 1969; Pilz 1996b). Official testing rules recommend tetrazolium staining as the first choice in testing, followed by germination in sand at 30 °C for 28 days after 270 days of stratification (ISTA 1993). Cutting tests are also recommended for rapid viability checks. After a seed is carefully split in half with sharp knife or scalpel, the embryo and megagametophyte tissue can be examined. If an embryo is opaque and developed, with visible cotyledon buds, and gametophyte tissue is white and fills the seed cavity, the seed should be considered mature and viable. A tetrazolium test for viability requires cutting seeds to expose tissue, staining for about 24 to 48 hours, then cutting out the embryos. A seed is considered viable if all of the embryo and endosperm is stained (Edwards 1987). Removing embryos from Pacific yew seeds and culturing them on nutrient medium with an energy source such as 2% sucrose has resulted in germination of 70 to 100%. Cleaned, mature seeds showed high germination whether seeds were fresh, cold stored, or stratified (Vance 1995). Embryo germination was shown to improve with a 14-hour photoperiod and up to 50 days of cold treatment in *in vitro* germination tests of embryos from English and Japanese yews (Flores and others 1993). Test results for 3 species are given in table 4.

Figure 4—*Taxus baccata*, English yew: seedling development 1, 8, 12, 22, and 39 days after germination.



Nursery practices. Freshly collected yew seeds can be sown in late summer or early fall of the year of collection, whereas stratified seeds can be sown in the spring of the year following collection. The seeds should be covered with about 1 to 2 cm (.4 to .8 in) of soil, and mulching the seedbed is beneficial (Steinfeld 1993a). Beds should be shaded during the summer. Even with these treatments many seeds often will not germinate until the second spring (Heit 1969; Steinfeld 1993a). Seedlings should be shaded after they emerge the first spring and summer. Rabbits have been observed feeding on Pacific yew seedlings in the bareroot beds at the USDA Forest Service's J. Herbert Stone Nursery at Central Point, Oregon (Steinfeld 1993b). Birds eat seeds, and germinants may be susceptible to damping-off fungi (*Fusarium* spp.). Although most ornamental yews are propagated by cuttings, seedlings of the Japanese yew cultivar 'Capitata' are germinated from seeds after 3 months of warm stratification (20 °C) followed by 4 months at 5 °C (Hartmann and others 1990). Seedlings are grown 2 to 3 years in seedbeds in a poly house, followed by 2 to 3 more years in liner beds, then 3 or 4 years in a nursery field

Table 4—*Taxus*, yew: stratification periods, germination test conditions, and results

	Germination test conditions					Germinative capacity		
	Stratification (days)		Temp (°C)			Avg	Range	
Species	Warm	Cold	Day	Night	Days	(%)	(%)	Samples
T. baccata	—	—	16	10	—	67	47–70	12
	120	365	10–16	10–16	60	47	—	1
T. brevifolia	—	—	30	20	60	55	50–99	3
T. cuspidata	120	365	10–16	10–16	60	68	—	1

Source: Rudolf (1974).

before they are of salable size (Hartmann and others 1990; Shugert 1994). In the first 3 years, 55% shade is used from mid-June until November to reduce stress (Shugert 1994). Young yew plants are susceptible to root weevils. Commercial preparation of nematodes that are effective against weevil larvae can be applied in early spring when soil temperatures reach 7 °C.

All yew species can be successfully propagated by rooting cuttings, and most commercial cultivars are produced this way. Successful stecklings from Pacific, Canada, Florida, and Honduran yews were obtained by rooting cuttings in a greenhouse under shaded conditions, on benches that had bottom heat of about 21 °C, an overhead mist system to maintain high humidity, and cool air temperatures (Hartmann and others 1990; Suszka 1978). On 1- to 2-year-old stems, from healthy branch tips, cuttings should be clipped at an angle and needles removed from the clipped end. Cutting length varies depending on the branch but may range from 10 to 20 cm (Chadwick and Keen 1976). The clipped tip should be dipped in a solution containing a root-promoting compound such as indole B-indolebutyric acid (IBA) or a-naphthalenacetic acid (NAA) and a fungicide, then stuck to a depth of about 3 cm (1.2 in) in rooting medium. Using 5,000 to 10,000 ppm of IBA dissolved in 50% ethanol and dipping cuttings quickly achieves satisfactory rooting (Hartmann and others 1990). The medium should hold the cuttings, maintain a high moisture content, and be well drained. A mixture of sphagnum peat moss, coarse vermiculite, and perlite or sand will enhance rootability and promote a desirable root system (Copes 1977). If Pacific yew cuttings are stuck in the winter, rooting may begin to occur within 4 to 6 weeks, depending upon species and cultivar but may also take up to 3 or more months. Rooting ability varies widely by clone or cultivar and by the time of year that yews are propagated. Clonally propagated plants should only be used where genetic selection for desired traits is needed in a cultivated setting. Seedlings are preferred over rooted cuttings for reforestation because they have genetic variation that more nearly approximates that of wild populations.

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Verbenaceae—Verbena family

Tectona grandis L. f.

teak

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Growth habit, occurrence, and use. Native to Southeast Asia in India, Myamar (Burma), Thailand, and Indochina, teak is the only important species of the 3 in the genus *Tectona* (Schubert 1974). It is a large deciduous tree that reaches maximum heights of 30 to 40 m. It grows best in warm, moist tropical climates with 1,250 to 3,000 mm of mean annual precipitation and a marked dry season of 3 to 6 months (Webb and others 1984). Teak has probably been cultivated for centuries in Asia and has been planted for timber production in India and Burma since at least 1840 (Troup 1921). In the Western Hemisphere, teak has been planted since about 1900, beginning in the Caribbean region (Marshall 1929; Moldenke 1935). Because it is a tropical species, in the continental United States, it grows successfully only in southern Florida. Adaptability trials have been successful in Hawaii (Whitesell and Walters 1976). About 130 ha of teak plantations have been established in Puerto Rico and the U.S. Virgin Islands (Weaver 1993). Teak wood is famous the world over for its strength, durability, dimensional stability, working qualities, and the fact that it does not cause corrosion when in contact with metal (Kukachka 1970; Troup 1921). It is currently used for shipbuilding, fine furniture, trim, decorative objects, veneer for decorative plywood, posts, poles, and fuel (Kukachka 1970; Webb and others 1984).

Geographical races of teak have been distinguished by differences in stem form and rate of growth (Champion 1933). These are not recognized botanically even as varieties, but it is most important when establishing plantations to use seeds from a race that will grow well under local conditions (Beard 1943; Champion 1933; Laurie 1938). In Trinidad, trees grown from seeds of Burmese origin have been more satisfactory than those grown from seeds of Indian origin (Beard 1943).

Flowering and fruiting. The small white, perfect flowers of teak are borne on short pedicels, in large erect terminal panicles, about 2 months after the dry season has ended and the large obovate leaves have emerged. The dates vary somewhat depending on the climatic regime, but flowering generally takes place for several months between June and September, and the fruits ripen 2 $^1/_2$ to 3 months later (Chable 1969; Mahapol 1954; Troup 1921; White and Cameron nd). The fruits gradually fall to the ground during the following dry season. The fruit consists of a subglobose, 4-lobed, hard bony stone about 1.2 cm in diameter, surrounded by a thick felty, light brown covering (figure 1), the whole enclosed in an inflated bladder-like papery involucre. The stone (often called a nut) contains 1 to 3, rarely 4, seeds (figure 2) and has a central cavity, giving the appearance of a fifth cell. Schubert (1974) found that the average number of seeds per stone was 1.7. In a survey of the fruits from 23 provenances in India, an average of 51% of the fruits were found to have no seeds, 35% had 1 seed, 12% had 2 seeds, 2% had 3 seeds, and 0.4% had 4 seeds per fruit (Gupta and Kumar 1976).

Figure 1—*Tectona grandis*, teak: (**top**) and side (**bottom**) views of fruits with their bladder-like involucres removed.

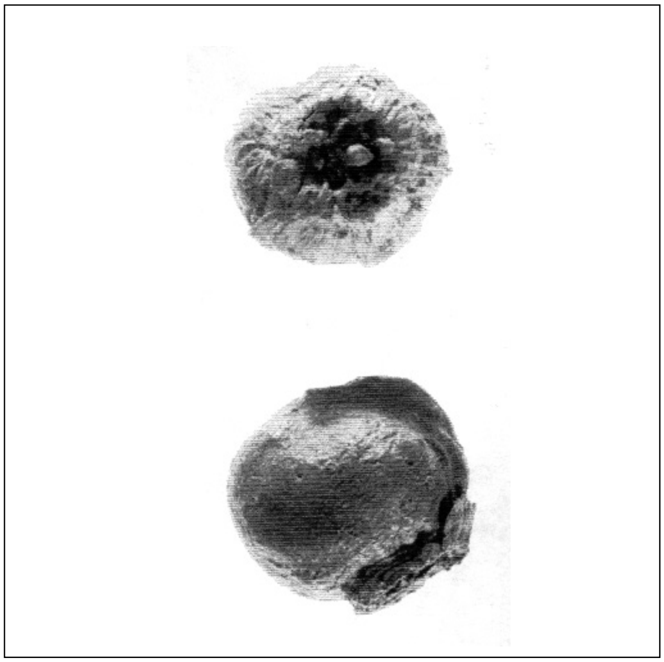
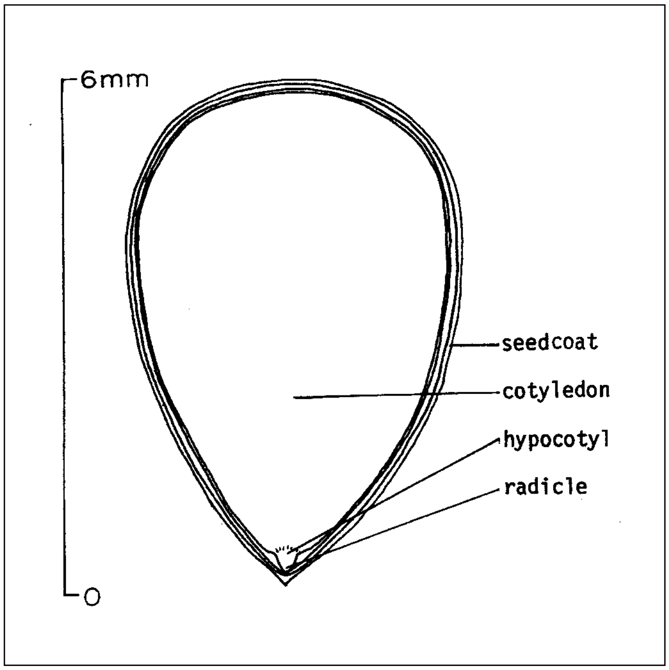


Figure 2—*Tectona grandis*, teak: longitudinal section through a seed.



Collection, extraction, and storage. Teak has borne viable seeds when only 3 years old (Schubert 1974), and good seedcrops are produced by plantations less than 20 years old (Troup 1921). The bladder-like involucre turns from green to brown when the seeds are ripe. The fruits can be swept up from the ground beneath the trees as they fall or else clipped with pruning poles or shaken from the branches. Drying can be completed by spreading the fruits on racks in the sun. For convenience in handling and storage, the involucre can be removed in a mechanical dehusker or by working a cloth bag half-filled with dried fruits against the ground with a foot and then winnowing to separate the fruits from the chaff. Teak fruits in Honduras average 705/kg (320/lb) with the involucres intact and 880/kg (400/lb) with the involucres removed (Chable 1969). In other parts of the world, the number of clean fruits per weight varies from a low of 880 to a high of 3,070/kg (400 to 1,400/lb) (Champion and Brasnett 1958; Parry 1956). The seeds make up about 3% of the weight of the cleaned fruits (Dabral 1976). Teak seeds are true orthodox in storage behavior and keep best at low temperatures and moisture contents. Keiding (1985) reported that seeds stored at 0 to 4 °C and about 12% moisture for 7 years lost no viability. Seeds from fruits stored in sacks in dry warehouses retained their viability for about 2 years (Kushalappa 1977). Longer periods of storage have not been needed in most areas because teak produces good seedcrops almost every year (Mahapol 1954; Troup 1921).

Germination tests. Cut tests of fruits on 56 collections from across the range of teak revealed a potential mean viability of 71% and ranged from 40 to 96% (Danish/FAO Forest Tree Seed Centre 1973). Laboratory germination tests should be carried out in sand at a constant 30 °C for 28 days. Pretreatment to stimulate germination should be 6 repetitions of soaking the fruits in water, followed by 3 days of drying (ISTA 1993). Germination in nursery beds in various parts of the world has varied from 0 to 96% in periods varying from 10 days to 3 months. Seeds extracted from the fruits and treated with fungicide gave a germination of 54% in 12 days (Dabral 1976). Because it is difficult to extract teak seeds from their fruits and untreated teak fruits give protracted, often low and unpredictable germination, some pre-treatment is usually applied to fruits. Various pretreatments to hasten or improve germination have been used. Soaking the fruits in water for several days, or alternate wetting and drying as in laboratory testing, have proven effective (Schubert 1959; Troup 1921; White and Cameron nd). In one test, clean fruits were pretreated by 5 cycles of alternate soaking in water for 24 hours and drying in the sun for 48 hours and then sown. Germination began 18 days after sowing and continued to increase for 15 days, after which it gradually decreased. Germination 68 days after sowing was 61% of the total number of fruits sown (Schubert 1974). Weathering of the epicarp and mesocarp aids germination. Seeds inoculated with *Scytalidium* sp. (a cellulolytic fungus isolated from teak litter), 0 and kept moist for 21 days had 96% germination compared to 20% for uninoculated control (Dadwal and Jamaluddin 1988). Increases in germination of 5 to 12% over controls (21% germination) were obtained with treatments of IAA and GA alone and in combination at various concentrations (Uanikrishnan and Rajeeve 1990). A novel method reported from Thailand is to expose the fruits to ants for 1 to 2 weeks: they attack and remove the felty covering and thus speed up germination without loss of viability (Bryndum 1966). Soaking fruits from 11 Indian provenances in a nutrient solution resulted in a higher seedling yield (34%) than control (18%), water soak (30%) or scarification (28%). It is felt that nutrient deficiencies in some of the sources resulted in lower germination or early seedling failure (Gupta and Pattanath 1975). A temperature of 30 °C appears to be optimal for germinating teak seeds (Dabral 1976). Some seeds that were stored for several months germinated better than fresh seeds (Champion and Brasnett 1958; Mahapol 1954; Troup 1921), probably because seeds need a period of after-ripening (Coster 1933). Because they tend to have a greater number of seeds per fruit, larger fruits yield a significantly higher number of seedlings per fruit. It is recommended that fruits smaller than 14 mm in diameter be culled (Banik 1977). Seeds from dry regions frequently are more difficult to germinate (Troup 1921). Germination is epigeal (Troup 1921).

Nursery practice. Teak fruits are usually broadcast in nurserybeds and covered with 1.2 to 2.5 cm ($^1/_2$ to 1 in) of sand, soil, or sawdust (Schubert 1956; White and Cameron nd). A seedling yield of about 25% can be expected from good seedlots (White and Cameron nd). The beds should be watered just enough to keep them moist. Once the seedlings have become established, watering should gradually be reduced. Field planting is generally done with "stump" plants (seedlings with the tops removed) or potted plants grown in plastic nursery bags. The stump plants are grown in the nursery until they reach 1.2 to 2.5 cm ($^1/_2$ to 1 in) in diameter at the root collar; then they are top-pruned to about 2.5 cm (1 in) and root-pruned to 18 or 20 cm (7.0 to 7.9 in) in length (Schubert 1956; White and Cameron nd). Ideally, plants of suitable size can be grown in 6 to 9 months. In Thailand (Kushalappa 1977) and India (Gupta and Pattanath 1975) at least some nurseries undercut the beds and remove seedlings large enough for stump plants after 1 year and allow the rest to grow another year when the whole bed is harvested. Sowing of the nurserybeds should be timed so that the proper size is reached in time for planting at the start of the rainy season. Another approach is to harvest in the dry season and store the dormant stumps in beds of dry sand for 3 months before planting at the start of the wet season (Kushalappa 1977). Direct seeding into prepared seed spots is practiced, but early growth is slow and often high mortality results (Weaver 1993). Teak can also be reproduced by coppicing, because cut stumps produce very vigorous sprouts.

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T

Asteraceae—Aster family

Tetradymia DC.

horsebrush

Lee E. Eddleman

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Growth habit, occurrence and use. *Tetradymia* (horsebrush) is a rather low-growing, multi-branched unarmed or spiny shrub, found either as well-scattered individuals or as small colonies mixed in with other vegetation. Some species may reach heights of 2 to 2.5 m but they are more commonly 1 m or less. Reproduction is from wind-dispersed seeds and from sprouting of root crowns and rhizomes in longspine horsebrush, hairy horsebrush, spiny horsebrush, and cotton horsebrush (Hartman 1984; McArthur and others 1979; Mozingo 1987; Strother 1974). Eight species (table 1) are found, primarily in the intermountain region and its fringe areas, and 2 species are found in southern California and Baja California (McArthur and others 1979; Strother 1974). Elevational range is from 800 to 2,400 m, although the southern California species range downward to 300 m. Horsebrush is commonly associated with the sagebrush vegetation type, but the genus has widespread occurrence from barren slopes and alkaline plains upward into the piñyon–juniper and yellow pine types.

Horsebrush provides ground cover and soil stability. It is generally considered of low forage value, although buds and new leaders are consumed by cattle, sheep, goats, antelope (*Antilocapra americana*), and mule deer (*Odocoileus hemionus*) (McArthur and others 1979). Most species are

Table 1—*Tetradymia,* horsebrush: nomenclature and occurrence

Scientific name & synonym(s)	Common name	Occurrence
***T. argyraea* Munz & Roos**	**striped horsebrush,** striped cottonthorn	Mountains of E Riverside & San Bernadino Cos., California
***T. axillaris* A. Nels.** *T.a.* var. *axillaris* *T.a.* var. *longispina* (M. E. Jones) Strother	**longspine horsebrush**	S Nevada into Inyo Co., California; S California
***T. canescens* DC.** *T. inermis* Nutt.; *T. multicaulis* A. Nels. *T. linearis* Rydb.	**gray horsebrush,** spineless horsebrush, common horsebrush	S British Columbia to S California E of Cascades–Sierra Nevada and from S Saskatchewan to N Arizona
***T. comosa* Gray**	**hairy horsebrush**	SW California to N Baja California
***T. filifolia* Greene**	**threadleaf horsebrush**	Central New Mexico
***T. glabrata* Torr. & Gray**	**smooth horsebrush,** littleleaf horsebrush	Great Basin, SE Oregon & SW Idaho, Utah, Nevada, to S California, mostly E of Sierra Nevada
***T. nuttallii* Torr. & Gray** *T. spinosa* Nutt. x *T. permixta* Payson	**Nuttall horsebrush**	SE Wyoming across central & N Utah to NE Nevada
***T. spinosa* Hook. & Arn.** *Lagothamnus ambiguus* Nutt. *L. microphyllus* Nutt.	**spiny horsebrush,** cottonthorn horsebrush, catclaw horsebrush, shortspine horsebrush, thorny horsebrush	SE Oregon, S Idaho, SW Montana S across W Wyoming & and Colorado, NW Arizona, W to Sierra Nevada
***T. stenolepis* Greene**	**Mojave horsebrush**	S California to extreme S tip of Nevada
***T. tetrameres* (Blake) Strother** *T. comosa* Gray ssp. *tetrameres* Blake	**cotton horsebrush,** four-part horsebrush, dune horsebrush	Central N Nevada SW to Mono Co., California

Sources: Cronquest (1994), McArthur and others (1979), Mozingo (1987), Strother (1974).

poisonous to sheep, especially smooth horsebrush (Johnson 1974; Kingsbury 1964). Flowers are used by small moths, bees, flies, and beetles (McArthur and others 1979). Gelechiid moths form galls in leaves and stems (Hartman 1984). Smooth horsebrush is considered ideal for desert landscaping because its leaves develop early and are dropped by mid-summer (Mozingo 1987). Late-season flowering species of horsebrush provide an attractive contrast to the vegetation types of dry areas.

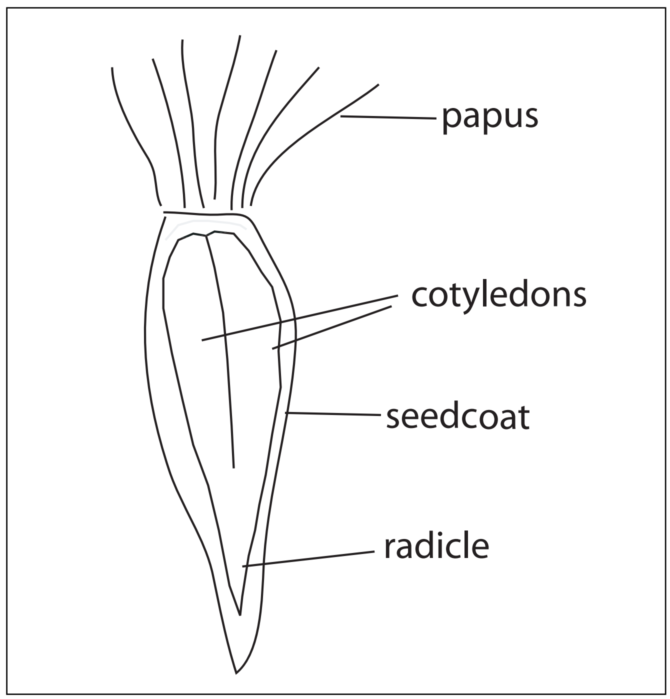
Flowering and fruiting. Horsebrush flowers are borne in heads of 4 to 8 florets each and are located either in the axil of primary leaves or are clustered as dense racemes or corymbs at the tips of branches. Flowering begins as early as April and may last into September. Horsebrush species flower at the following times: striped horsebrush, late June to early August; longspine horsebrush, April and May; gray horsebrush, late May through September; hairy horsebrush, June through mid-August; threadleaf horsebrush, July; smooth horsebrush, May through July; Nuttall horsebrush, late May and June; spiny horsebrush, April through August; Mojave horsebrush, late May through early August; and cotton horsebrush, June and July (Cronquist and others 1994; Mozingo 1987; Strother 1974). Longspine and smooth horsebrushes are the first to flower, where as gray horsebrush flowers from late May through mid-September and has the unique characteristic (among the horsebrush species) of flowering earliest in the north and progressively later southward (McArthur and others 1979; Strother 1974).

Collection, extraction, and cleaning. Horsebrush achenes (figures 1 and 2) are more or less hairy and sometimes glabrous; they possess a well-developed pappus of bristles. As in similar plant forms (Eddleman 1977), the seeds may be hand-stripped or knocked from the head onto a canvas. Mature achenes from which the hairs have been removed have a light to medium reddish brown cast and a parismatic to fusiform shape. Cleaned seeds per weight are reported at 309/g (140,000/lb) for gray horsebrush (McArthur and others 1979) and may be less for the larger seeded species—Nuttall, spiny, Mojave, and cotton horsebrushes.

Germination. Germination is poor for gray horsebrush (Stark 1966), and only 2% of spiny horsebrush seeds germinated in one test (Swingle 1939). Some germination may occur without pretreatment, but prechilling seeds for 4 to 6 weeks is reported to help germination (Young and Young 1992).

Figure 1—*Tetradymia* horsebrush: seeds. *T. comosa* **(left),** *T. spinosa* **(right)**.

Figure 2—*Tetradymia* horsebrush: *T. comosa* longitudinal section through achene.



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Malvaceae—Mallow family

Thespesia Soland. ex Correa

thespesia

John K. Francis

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Species, occurrence, and growth habit. There are 17 species of *Thespesia,* all trees or shrubs (Howard 1989). Two are of particular interest. *Thespesia populnea* (L.) Soland. ex Correa—with botanical synonyms *Hibiscus populneus* L. and *T. lampas* (Cav.) Dalz. ex. Dalz. & Gibson—is known locally as portiatree, seaside mahoe, *emajagüilla, milo*, and many other names (Little and Skolmen 1989; Parrotta 1994). Portiatree is native to tropical shores from East Africa to Polynesia. It has naturalized (and is sometimes considered invasive) and is planted in coastal areas throughout the tropics. Portiatree is a small tree in moist habitats, although it is often shrubby on dry or salty coastal soils.

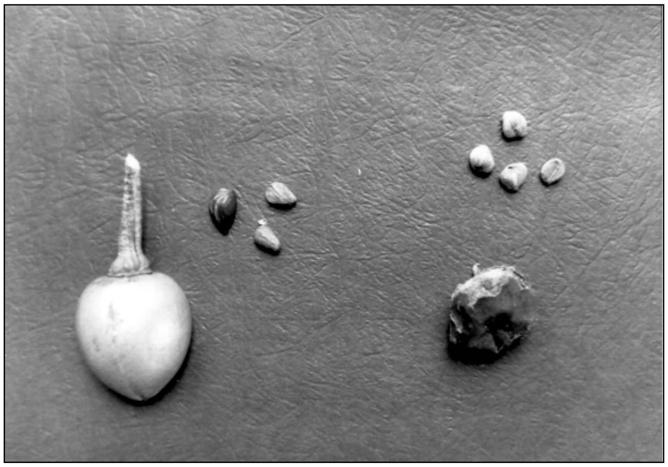
Thespesia grandiflora DC.—known as *maga*—is a small to medium-sized tree with a straight stem that is endemic to Puerto Rico (Francis 1989). This species has been referred to in the literature by the botanical synonyms *Montezuma speciocissima* Sessé & Moc., *M. grandiflora* DC., and *Maga grandiflora* (DC.) Urban (Francis 1989).

Use. Portiatree is planted as an ornamental throughout the tropics, especially in coastal areas. Its manageable size, heart-shaped, yellow-green leaves, and yellow flowers endear it to many. More than for any other reason, portiatree succeeds as an ornamental because it can grow on almost any soil. Maga is planted as an ornamental in Florida, Hawaii, Puerto Rico, and several other locations (Little and Wadsworth 1964; Neal 1965). Although its dark-green foliage is very attractive, its large (15 cm) dark pink flowers are its principal asset. Maga requires fertile soils and does not tolerate compaction. The wood of both species is dark reddish brown to chocolate brown, moderately heavy, and moderately hard, with excellent working properties. The small amounts of portiatree wood available fetch high prices and are used for carving, furniture, and posts. The small amounts of maga harvested are used for making musical instruments, furniture, and craft items. Seeds of portiatree are widely used for medicinal purposes (Little and Skolmen 1989; Parrotta 1994).

Flowering and fruiting. Open-grown maga are reported to begin flowering when 5 to 10 years old (Francis 1989); portiatree flowers even earlier. Except in dry areas and seasons of drought, flowering and fruiting of both species proceeds throughout the year (Francis 1989; Parrotta 1994). The fruits of portiatree are flattened, leathery 5-celled capsules 2.5 to 4.0 cm in diameter and 2 cm long (Rashid 1975). They may remain attached to the tree for some time. A sample of 50 fruits from Puerto Rico contained from 1 to 11 seeds/fruit with an average of 5.7 seeds/fruit (Parrotta 1994). The seeds are hairy, 1 cm long, and 0.6 cm broad (figure 1). Reported weights of air-dried seedlots range from 3,500 to 6,700/kg (1,600 to 3,000/lb) (Francis and Rodríguez 1993; Parrotta 1994; Rashid 1975; Von Carlowitz 1986). The fruit of maga is smooth and green, subglobose, and 3 to 5 cm in diameter. From 1 to 12 brown seeds are embedded within a white, fleshy matrix. Fresh seeds numbered 2,500/kg (1,100/ lb); air-dried seeds, 3,900 seeds/kg (1,800/lb) (Francis 1989). The seeds of portiatree are dispersed by wind and water (Parrotta 1994). Maga depends upon fruit bats and birds for dispersal (Francis 1989).

Collection, cleaning, and storage. Quantities of portiatree fruits can be easily picked off the ground under bear-

Figure 1—*Thespesia*, thespesia: fruits and seeds of *T. grandiflora*, maga (**left**), and *T. populnea*, portiatree (**right**).



ing trees, or they can be picked by hand or clipped with a pruning pole from the branches. The fruits are mature when they have turned black (Rashid 1975). Accumulating quantities of maga seeds is more difficult. Maga fruits can be clipped from the trees when they reach full size (no color change is observed). Fruits that are still hard should be left for 2 or 3 days and will continue to ripen. If not eaten by bats and birds, the fruits fall soon after ripening and can be picked up from the ground. Because bats and birds drop the seeds as they consume the fruits, seeds can be collected from the ground under bearing trees or beneath nearby perch trees. Good seeds have a cinnamon-brown color with a waxy luster and are free of fungal spots. Lighter or darker colors denote immaturity or overmaturity and loss of viability (Marrero 1949). Nursery workers normally clean the seeds by hand, a fairly rapid process. Cleaning with macerators may not be possible due to the fragile nature of the seeds, especially those of maga. Seeds of portiatree are apparently recalcitrant but somewhat resistant to drying and can be stored in sealed containers for weeks to months under refrigeration (4 °C). The seeds of maga are highly recalcitrant. The folded cotyledons (figure 2) are active and turn green within the seed as germination begins. The seeds begin germinating 5 to 7 days after the fruit ripens (Francis 1989). Many of the seeds picked up from the ground, either loose or within rotting fruits, already have the radicle exposed. It is best to place moist paper towels or other moistened material in the collection container and sow the seeds as soon as possible. Viability of maga seeds can be extended to nearly 4 months by drying to 62.5% moisture and storing at 2 to 4 °C (Marrero 1942).

Germination. No pregermination treatments are necessary. Seeds of portiatree should be sown in sandy media and lightly covered (Parrotta 1994). From 65 to 79% of fresh seeds germinate, beginning in 8 days and continuing over a 9-week period (Francis and Rodríguez 1993; Ricardi and others 1977; Parrotta 1994). Maga seeds may be sown and lightly covered in ordinary potting mix. Marrero (1942) reported that, although 70 to 80% of fresh seeds germinated, only 20% of seeds stored at room temperature for 2 weeks germinated. Francis and Rodríguez (1993) reported 80% germination beginning 6 days after sowing. Germination of both species is epigeal (figure 3) (Francis 1989; Parrotta 1994).

Nursery practice. Ordinary nursery practice is to germinate seeds in germination trays or beds and transplant seedlings into containers (pots or plastic nursery bags) after the first true leaves emerge. Portiatree seedlings reach 15 cm (6 in) in height about 3 months after sowing (Parrotta 1994). Moving portiatree seedlings into full sunlight after they are established in the pots is recommended. Rooted cuttings are also used to produce portiatree stock. Maga seedlings develop rapidly in partial shade, reaching 20 cm (8 in) in 3 months and 40 cm (16 in) in 6 months (Francis 1989). Maga seedlings should be moved into full sun a few weeks before outplanting. Seedling stock of either species from 15 to 50 cm (6 to 20 in) can be used to establish plantations. Trees destined to become ornamentals are often grown in pots until they attain 1 to 2 m (39 to 79 in) in height. Wildlings are sometimes collected, potted, and allowed to rebuild their root system before outplanting.

Figure 2—*Thespesia grandiflora*, maga: seed cut in longitudinal section.

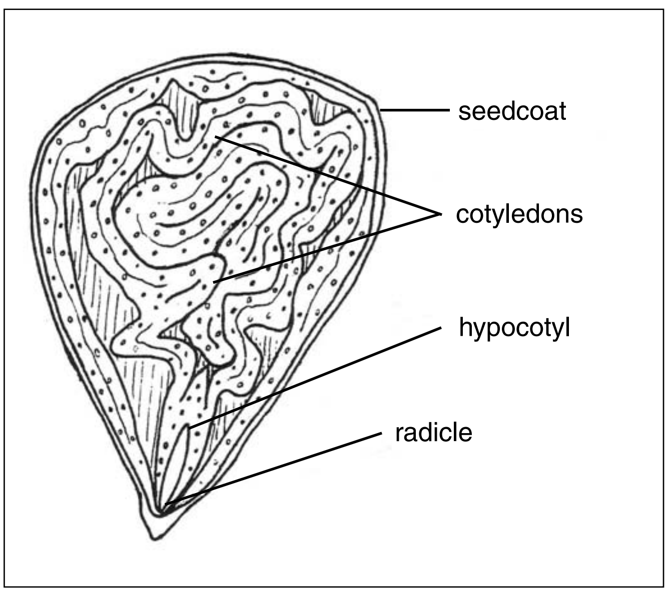
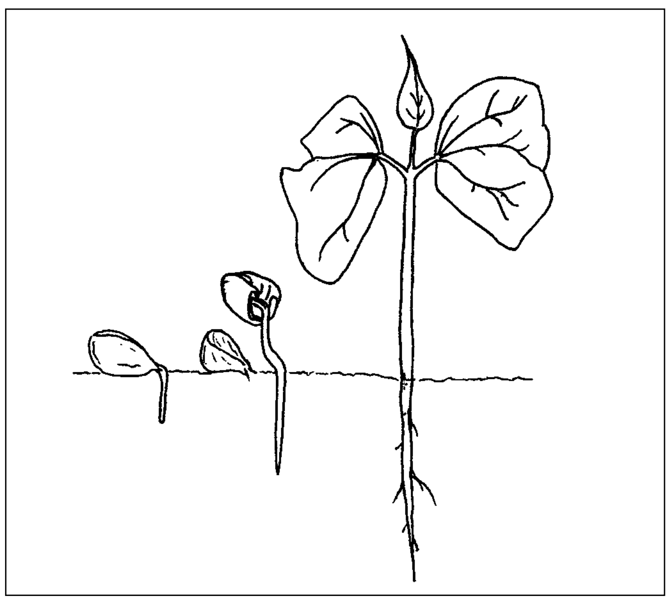


Figure 3—*Thespesia grandiflora*, maga: germination and seedling development.



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T

Cupressaceae—Cypress family

Thuja L.

arborvitae

Gary J. Brand and C. S. Schopmeyer

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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 Mountains in Oregon and Washington; and the Rocky Mountains in southeastern British Columbia, northeastern Washington, northern Idaho, and western Montana (Little 1971).

Table 1—*Thuja,* arborvitae: nomenclature and occurrence

Scientific name & synonym(s)	Common name(s)	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).

The 3 Asian species listed (table 1) are only planted for ornamental purposes in the Untied States. 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 are browsed extensively by 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 thuja 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).

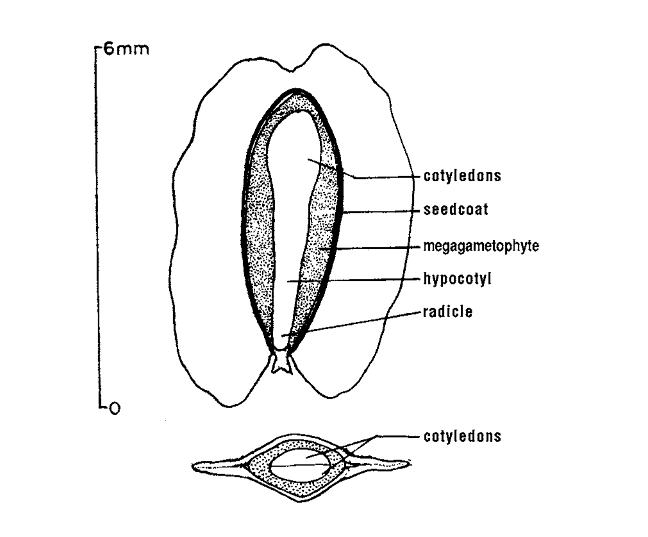
Flowering and fruiting. Male and female flowers are borne on the same tree but usually on separate twigs or branchlets (Schopmeyer 1974). Flower initiation begins in spring to early summer, development ceases in the fall, pollen is shed in late winter to early spring, and fertilized cones are mature by fall (Owens and Molder 1984). Female flowers form near the tips of vigorous lateral branches (figure 1) and are usually higher on the tree than the male flowers. The presence of low numbers of cone buds in the dormant season indicates 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. 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 (figures 2 and 3). 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

Figure 1—*Thuja*, arborvitae: mature cones of *T. occidentalis*, northern white-cedar, with female cone buds on branch tips above the brown mature cones.

Figure 2—*Thuja*, arborvitae: mature cones and seeds of *T. occidentalis*, northern white-cedar.

Figure 3—*Thuja occidentalis*, northern white-cedar: longitudinal section **(top)**, and transverse section showing 2 cotyledons **(bottom)**.



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 °C and a relative humidity of 38% (Schopmeyer 1974). Kiln temperatures below 43 °C 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 °C (Edwards 1986), 18 to 20 hours at 41 °C (Owens and Molder 1984), or 27 °C 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 de-winged (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.

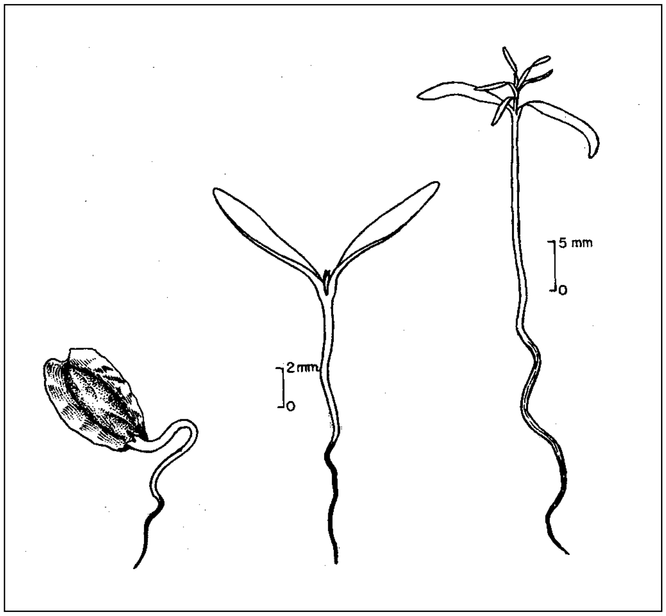
Arborvitae seeds are orthodox in storage behavior. Seeds should be stored in fiber containers with plastic or foil liners (Gordon and others 1991). Seeds stored at a moisture content of 5 to 10% in sealed containers at 0 to 5 °C should remain viable for up to 5 years (Gordon and others 1991). For longer periods, storage at –18 °C 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 °C (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 °C; no pretreatment is recommended. Germination is epigeal (figure 4). 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 nurserybeds 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 just before sowing,

Figure 4—*Thuja occidentalis*, northern white-cedar: seedling development at 1, 5, and 25 days after germination.



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 °C 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 ($^1/_8$ to $^3/_8$ 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 seeds 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 out-planting. Seeds sown in the containers are covered with a thin layer (about 0.3 cm, or $^1/_8$ 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 western 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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Tiliaceae—Linden family

Tilia L.

linden or basswood

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Growth habit, occurrence, and uses. The genus *Tilia* L.—linden or basswood—consists of about 40 species of large or medium-sized, deciduous trees that are indigenous to the temperate Northern Hemisphere. *Tilia* is the only genus of its family, Tiliaceae. Species reach their maximum size in loamy, moist, fertile soil, but they tolerate poor soils, pollution, windy conditions, and transplanting and can be grown in full sun or partial shade (Dirr 1990; Haller 1995; Kunneman and Albers 1991). Lindens possess a well-developed root system and are long lived, with some species living between 500 to 1,000 years (Haller 1995; Kunneman and Albers 1991). Table 1 lists species native to North America as well as widely grown non-native species.

Few shade trees vary so greatly in shape, leaf size, and growth rate as do the lindens (Flemer 1980). They generally possess a uniform globular crown and smooth, silver-gray bark that becomes fissured on old trees (table 2). The winter form is striking, with stiff, erect branches growing upward at 30° angles from a thick trunk (Burgess 1991). Considerable differences in growth habit exist among cultivars of littleleaf linden, ranging from the very dense, formal pyramidal habit of 'Greenspire', the dense upright oval shape of 'Chancellor', to the more open, informal oval habit of 'Fairview' (Pellett and others 1988).

There is much disagreement among taxonomists as to correct identification of species, and there are numerous names in the literature that are no longer recognized by many botanists. For example, *T. monticola* Sarg. and *T. michauxii* (Nutt.) Sarg. are sometimes seen in the literature or listed as specimens in botanical gardens, but they are now considered to be varieties of white basswood—*T. americana* var. *heterophylla* (Venten.) Loud.—recognized previously as *T. heterophylla* Venten. (Ayers 1993; Rehder 1990).

Table 1—*Tilia,* linden: nomenclature, and occurrences

Scientific name & synonym(s)	Common name(s)	Occurrence
***T. americana* L.** *T. glabra* Venten.	**American linden,** basswood, whitewood, American lime, bee-tree	New Brunswick S to Virginia & Texas
***T. americana* var. *caroliniana* (P. Mill.) Castigl.**	**Carolina basswood**	SE US
***T. americana* var. *heterophylla* (Venten.) Loud.**	**white basswood**	West Virginia to Florida, W to Indiana & Alabama
***T. cordata* P. Mill.** *T. parviflora* J. F. Ehrh. ex Hoffm.)	**littleleaf linden,** small-leaved lime, European linden	Europe
***T. euchlora* K. Koch** *T. cordata* x *T. dasystyla*	**Crimean linden,** Caucasian lime	SE Europe & SW Asia
***T. europaea* L.** *T. cordata* x *T. platyphyllos* *T. intermedia* DC. *T. vulgaris* Hayne	**European linden,** common linden, lime	Europe
***T. mexicana* Schldl.**	**Mexican basswood**	Mexico
***T. petiolaris* DC.**	**pendent silver linden,** pendent white lime, weeping lime	SE Europe & W Asia
***T. platyphyllos* Scop.** *T. europaea* var. *grandiflora* Hort.	**bigleaf linden,** large-leaved lime, largeleaf linden	Europe to SW Asia
***T. tomentosa* Moench** *T. argentea* DC.	**silver linden,** European white linden	SW Europe & Asia

Sources: Dirr (1990), LHBH (1976), Plotnik (2000), Rehder (1990), RHS (1994).

Table 2—*Tilia,* linden: growth habit and general comments

Species	Growth habit & maximum height	General comments
T. americana	Tree to 40 m with numerous, slender, low-hung spreading branches; pyramidal when young, crown somewhat rounded at maturity	Flowers pale yellow in summer; bee plant; wood used for making expensive furniture & excelsior, inner bark used for fabric
T. a. var. *caroliniana*	Tree to 20 m; close to habit of *T. americana*	—
T. a. var. *heterophylla*	Tree to 30 m; crown conical	—
T. cordata	Tree to 30 m; pyramidal when young; upright-oval to pyramidal-rounded & densely branched in old age; crown outspread	Widely planted as a street tree; pollution-tolerant; excellent shade tree
T. euchlora	Tree to 20 m	Similar to *T. cordata*
T. europaea	Tree to 37 m	—
T. mexicana	Tree to 20 m	—
T. petiolaris	Tree to 23 m	Sometimes considered as a pendulous selection of *T. tomentosa*
T. platyphyllos	Tree to 40 m; crown conical to broadly conical	Not widely planted in the US
T. tomentosa	Tree to 27 m; pyramidal when young; upright-oval to pyramidal-oval in later years; crown dense	Can be grown effectively as a multi-stemmed specimen to highlight light gray, smooth bark; good street tree, tolerating heat & drought better than other lindens

Sources: Dirr (1990), LHBH (1976), Plotnik (2000), Rehder (1990), RHS (1994).

Lindens are generally not suitable for lumber because the wood is soft and rots easily. However, the soft, straight-grained and even-textured wood is ideal for woodcarving and is utilized to make musical instruments, piano keys, Venetian blinds, and veneer and can serve as a source of fiber (Haller 1995; Kunneman and Albers 1991). The wood does not produce splinters, thus making it ideal for tool handles. The inner bark (or "bast") consists of long, tough fibers that once were used in the production of cordage, mats, and clothing. The common names for the species—basswood, linden, and lime—are derived from this characteristic: *bast* gives us the name bastwood or basswood; *linden* and *lime* are thought to be derived from the Latin word for linen (Haller 1995). In addition, flowers of linden are quite fragrant and produce large quantities of nectar that is very attractive to bees. The flowers of European, bigleaf, and littleleaf lindens are brewed for tea (Bremness 1994). The nectar of some species is so overpowering that bees can be found inebriated on the ground beneath the tree (Haller 1995). The light-colored honey produced is world famous.

Lindens are used primarily as ornamental shade and street trees (table 2), more so in Europe than in the United States. For example, Berlin's most famous boulevard is named *"Unter den Linden"*. They are well-adapted to a broad range of soil and climatic conditions and are relatively free of major disease problems that may threaten the survival or landscape value of established trees (Pellett and others 1988). The European lindens—littleleaf, European, bigleaf, and silver lindens—have greater importance in landscape plantings in the United States because they are more tolerant and ornamental than American species such as American linden (Dirr 1990; Heit 1977). In addition, American linden becomes too large for the average home property and is better left in the forest (Dirr 1990). However, silver linden possesses a shallow root system and its canopy casts dense shade, making it unsuitable for underplanting (Burgess 1991).

Geographic races and hybrids. As mentioned previously, there is much disagreement among taxonomists as to correct identification of species. For example, there is debate whether white basswood is a southern race of American linden or a separate species. Also, hybridization between species occurs naturally and has given rise to variability among seedlings (Kunneman and Albers 1991). Of the more common hybrids, Crimean and European lindens are not considered superior landscape trees relative to littleleaf linden (Dirr 1990).

Flowering and fruiting. Perfect, fragrant, yellowish or whitish flowers that bloom in June or July are borne in short, pendulous cymes with stalks attached to a large thin-textured oblong bract. Trees and clonal groups of trees flower almost simultaneously over the exposed parts of their crowns. In each inflorescence, the terminal flower of the dichasium opens first and in warm weather is followed at intervals of a day by flowers on the branches of successive orders (Pigott and Huntley 1981). Trees usually flower within 5 to 15 years when grown from seed. Shortness of blooming period (several days to 2 weeks, depending on weather conditions) and lack of consistent flowering from year to year are problems for beekeepers harvesting honey (Ayers 1993). In particular, the American lindens have a reputation for not flowering every year. Some of the introduced species are more consistent (Ayers 1993).

Following pollination, temperatures must be > 15 °C for growth of the pollen tube and for fertilization to occur so that fruits will be produced (Pigott and Huntley 1981). Fruits are grayish, nut-like, round to egg-shaped capsules that mature in autumn but may persist on the tree into the winter. Each consists of a woody pericarp enclosing a single seed (but sometimes 2 to 4 seeds) (figures 1 and 2) (Brinkman 1974; Pigott and Huntley 1981). The pericarp consists of an outer layer of loose fibers forming a mat (or tomentum) and a broad region of thick-walled lignified fibers that are responsible for its hard, tough, woody character (Spaeth 1934). Fruits of American linden are tough and leathery, whereas those of littleleaf linden tend to be thinner and rather brittle (Heit 1967). Seeds possess a crustaceous seedcoat; a fleshy, yellowish endosperm; and a well-developed embryo (figures 2 and 3). Natural dispersion is primarily by wind and animals (Brinkman 1974).

Collection of fruits, seed extraction and cleaning. The ideal time to harvest fruits is early fall, when seed moisture content is approximately 16% (Vanstone 1982). During fruit ripening, moisture is lost from the seeds at a rate of 1 to 2% per day, so that seeds must be monitored closely. Pericarp color is a reliable indicator of moisture content in relation to germination. Fruits should be picked when the pericarp is turning from green to grayish-brown and before the pericarp becomes tough and leathery. Otherwise, seeds will require greater efforts during extraction and scarification. There is generally uniform ripening on any individual tree, but the exact date of ripening may vary by several weeks among trees (Vanstone 1978). Because fruits of lin-

Figure 1—*Tilia*, linden: fruits of *T. americana*, American linden (**top**) and *T. cordata*, littleleaf linden (**bottom**).

Figure 2—*Tilia cordata*, littleleaf linden: seed.

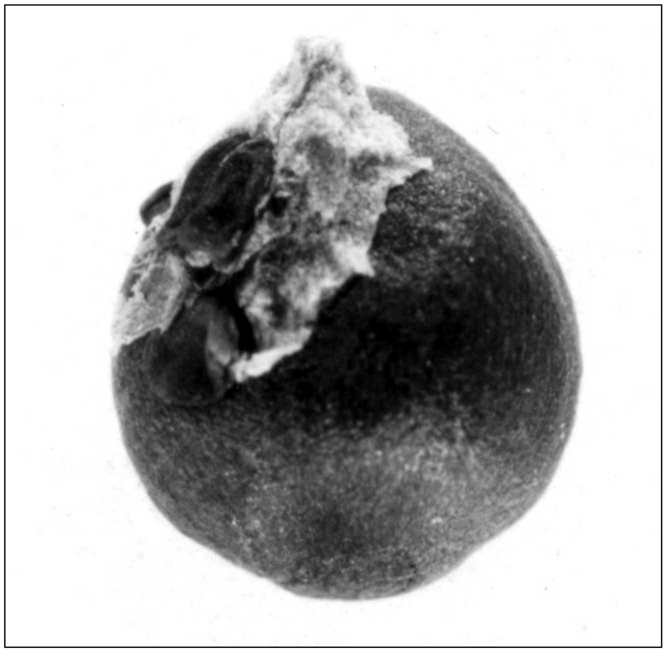
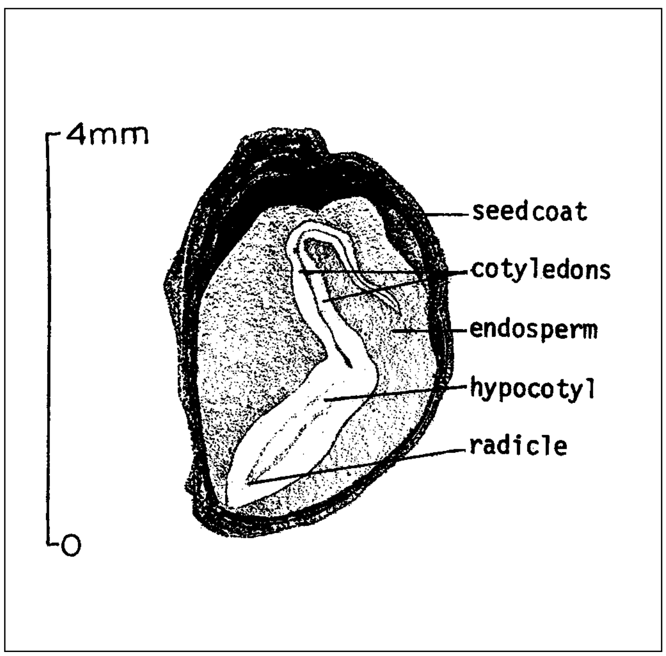


Figure 3—*Tilia americana*, American linden: longitudinal section of a seed.



den persist on the tree, fruit collection is often postponed until after maturity. After a heavy frost, fruits can be shaken from branches onto a canvas tarp and spread out to dry (Brinkman 1974).

Once fruits have been collected, bracts can be removed by flailing or passing the fruits through a de-winging machine. The hard pericarp must then be removed. Fruits of littleleaf and bigleaf lindens have prominent sutures that are helpful in the extraction process by serving as a breaking point for both mechanical and rubbing techniques (Heit 1977). Fruits of European and silver lindens can be handled similarly, and a combination of sieving, screening, and blowing can readily remove debris (Heit 1977). However, fruits of American linden have a hard, tough, leathery pericarp and must be run through a coffee grinder or a similar device or treated with acid to accomplish its removal (Heit 1977). Mechanical extraction of seeds is often difficult. Any crushing force sufficient to fracture the tough pericarp is likely to exert a shattering pressure on the brittle seedcoat (Spaeth 1934). Seed yields and size vary by species (table 3)

Storage. Seeds of the lindens are orthodox in storage behavior and should be stored in sealed containers at a moisture content of 8 to 12%. Seeds of American linden have retained their viability for 2 years when stored under dry conditions at room temperature and for 5 to 6 years when stored at 1 to 4 °C (Heit 1977).

Pregermination treatments. In addition to their tough pericarps, seeds of linden exhibit double dormancy and thus require both scarification and stratification (moist-prechilling) because of their impermeable seedcoat and dormant embryo, respectively. For seeds of littleleaf linden, Heit (1977) recommended a sulfuric acid treatment of 10 to 50 minutes at a temperature ranging from 23 to 27 °C. Colder temperatures required a longer duration of acid treatment. Because all species of linden and individual seedlots within the same species are variable in their percentage and degree of hardseededness, it is advisable to soak some seeds in water for 1 or 2 days to determine the degree of hardseededness before treating with acid. Ten to 20 minutes of acid treatment may be ideal for some seedlots, but 20 to 50 minutes would produce the best results for others. The degree of hardseededness depends on factors such as seed source, time of collection, and storage conditions, including temperature and relative humidity (Heit 1967, 1977). Other scarification treatments include mechanical scarification and hot water treatments, but neither are as good as acid scarification (Heit 1977). Freezing to –80 and –185 °C had little effect on the permeability of the seedcoat (Spaeth 1934). Surface sterilization with sodium hypochlorite (NaOCl) and ethanol proved to control seed pathogens but lowered germination percentages of littleleaf, bigleaf, and silver lindens (Magherini and Nin 1993).

In addition to scarification, stratification is essential for maximum germination and seedling production. Following scarification, seeds must be either fall-sown immediately or stratified at 1 to 3 °C for about 3 months before spring-sowing. Vanstone (1978) recommends stratification in a 1:1 mixture (by volume) of peat and sand containing 30% moisture by weight. Enzyme activity and levels of soluble proteins and amino acids in the seeds increase gradually during stratification at 4 °C (Pitel and others 1989). Nontreated seeds have been known to lie in the ground for over 5 years without germinating while still maintaining viability (Heit 1967). Bigleaf linden requires 3 to 5 months of warm stratification followed by 3 months of cold, and even this treatment does not guarantee high germination (Dirr and Heuser 1987). Flemer (1980) recommends burying seeds in a wooden box filled with damp sand and leaving the box outdoors during the winter. Boxes are then dug up the following fall and the seeds are sown. Seed treatments that consistently result in

Table 3—*Tilia,* linden: seed yield data

	Seed wt/fruit wt		Cleaned seeds/weight (x1,000)				
			Range		Average		
Species	kg/45.4 kg	lb/100 lb	/kg	/lb	/kg	/lb	Samples
T. americana	—	—	—	—	6.6	3	2
	34.1	75	6.6–17.6	3.0–8.0	11	5	15+
	—	—	20–32.1	9.1–14.6	—	—	—
T. cordata	36.3	80	24.9–38.3	11.3–17.4	30.4	13.8	57+
	—	—	48.8–65.1	22.2–29.6	—	—	—
T. x europaea	—	—	23.3–29.7	10.6–13.5	—	—	—
T. platyphyllos	—	—	25.1–30.6	11.4–13.9	—	—	—
T. tomentosa	—	—	20.0–25.1	9.1–11.4	—	—	—

Sources: Brinkman (1974), Heit (1977).

good germination for all species and seedlots have not been developed. Much variability exists among species and seedlots in regards to permeability of the pericarp and seedcoat, as well as stratification requirements.

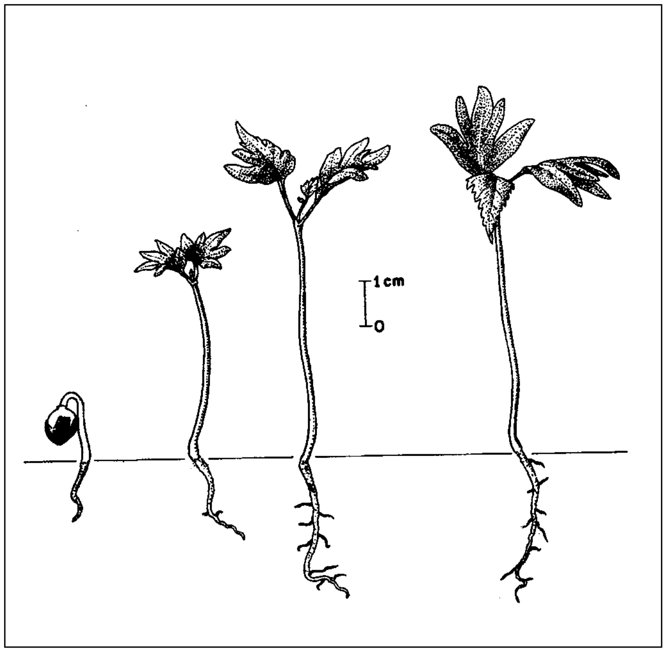
In Europe, dormancy in littleleaf linden is overcome by the use of warm incubation or acid scarification, followed by stratification (Suszka and others 1996). Fully imbibed seeds are first stored for 4 months at 20 to 25 °C (or scarified with concentrated sulfuric acid for 12 minutes), then stratified at 3 °C for 14 to 18 weeks. Stratification should be stopped when the first seeds start to germinate.This complete process may take 8 or 9 months.

Germination tests. Germination is epigeal (figure 4). Optimum germination occurs at temperatures above 20 °C (68 °F), but seeds will germinate at temperatures as low as 2 °C once stratification requirements have been satisfied (Spaeth 1934). Thus, seeds should be checked periodically for radicle emergence during stratification. Light is not required for germination (Heit 1967). The use of any stratification procedure requires far too much time to be used in routine germination testing, however, so rapid estimates of viability are recommended for this purpose. This can be done with tetrazolium staining, indigo-carmine staining, or excised embryo tests (ISTA 1996; Suszka and others 1996). However, these tests require removal of the pericarp and the seedcoat without damaging the embryo. Tetrazolium staining is the most common test. It requires soaking seeds in water for 18 to 24 hours, removing all or a large part of the seedcoat, and soaking the seeds in a 1% tetrazolium solution for 24 to 48 hours at 30 °C.

Pitel and Wang (1988) found that both the rate and percentage of germination of seeds of American linden were increased by treating scarified seeds with a solution of kinetin (1 mg/liter) and gibberellic acid (GA_3, 500 mg/liter. Over 90% germination was obtained after 60 to 80 days at 4 °C. However, GA did not improve germination percentage of seedlots of littleleaf, bigleaf, and silver linden (Magherini and Nin 1993). The conflicting results are likely due to the level of gibberellin present. Natural levels of GA exist in dormant, nonstratified seeds and a sudden increase in the quantity of gibberellin is observed from the sixth week of stratification (Nagy 1980). It is likely that a specific quantity, rather than just the presence of free gibberellins, is required to break dormancy and stimulate germination.

Traditionally, for an accurate germination test, the outer pericarp must be removed and the hard seeds must undergo scarification and stratification. However, excised embryos of American linden that were separated from the seedcoat and endosperm were able to germinate and grow when placed on an agar medium without any pretreatment (Vanstone 1982). If any of the endosperm was retained around the embryo, no growth took place, indicating an apparent lack of embryo dormancy, for the naked embryo will grow when it is separated from other parts of the seed. Some factor that restricts germination seems to be present in the endosperm and must be overcome before an intact seed can germinate. That factor would normally be overcome by stratification. The same result was obtained with bigleaf linden, for germination was induced by removing the endosperm tissue around the radicle (Nagy and Keri 1984).

Figure 4—*Tilia americana,* American linden: seedling development at 1 day and 3, 16, and 19 days after germination.



Nursery practice and seedling care. Most trees in culture are of seedling origin (Kunneman and Albers 1991). However, some are propagated by grafting, chip budding, layering, rooting winter hardwood or leafy softwood cuttings, or tissue culture (Flemer 1980; Howard 1995; Kunneman and Albers 1991). For grafting, seedling rootstocks are used, preferably of the same species as the scion, as incompatibility is a common phenomenon (Kunneman and Albers 1991). Named cultivars are grafted commonly in spring or budded in summer (LHBH 1976). Plants of littleleaf linden have been propagated by somatic embryogenesis initiated from immature zygotic embryos and then established successfully in soil (Chalupa 1990). Except for hybrids such as Crimean and European linden, all can be seed-propagated (Dirr and Heuser 1987).

Production by seed at a specified time is often relatively difficult (Dirr and Heuser 1987; Heit 1967). As described

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previously, seeds show delayed germination because of a tough pericarp, an impermeable seedcoat, and a dormant embryo. Seeds may remain in the ground for several years and never produce a good stand of seedlings. The degree of seedcoat hardness and embryo dormancy varies within and among seedlots for most species (Hartmann and others 2002). Also, germination is irregular, and unknown seed sources and hybridization between species have given rise to variability among seedlings (Kunneman and Albers 1991). In addition, Heit (1977) found that several lots of seeds of bigleaf and silver lindens from Europe contained high percentages of empty seeds, from 20 to 72% (Heit 1977). This condition should always be checked before sowing or treating seeds.

Mature fall-collected seeds may be sown in spring following scarification and stratification (see Pregermination treatments). An alternate method is to collect seeds early, before the pericarp turns brown and sow in the fall. Early seed collections may result in seeds that have soft seedcoats that do not require scarification (Heit 1977). However, some propagators have harvested early and obtained inconsistent results, with the seeds sometimes decaying. Late-harvested seeds may also be germinated the first season but require more treatment than seeds harvested at the ideal stage of maturity (Vanstone 1978).

Seeds are sown in shallow rows—6 to 13 mm ($^1/_4$ to $^1/_2$ in)—in beds and covered with sand to aid in seedling emergence. The emerging seedlings are very delicate and subject to sun scald, so lathe screens or shade netting over the seedbeds greatly improves seedling stands (Flemer 1980). Fall-sown seedbeds should be mulched, protected from rodent damage, and kept moist until germination begins in the spring (Vanstone 1978). Good stands of little-leaf, bigleaf, and silver lindens are normal, but seeds of American linden exhibit great variation in germination from year to year (Flemer 1980). When poor stands result, seedlings should be removed carefully so as not to disturb the bed, for additional germination often occurs the second year after planting. Seedlings are usually outplanted as 1+0 or 2+0 stock.

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Meliaceae—Mahogany family

Toona ciliata Roemer

Australian toon

Gerald A. Walters and John K. Francis

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Synonyms. *Toona australis* Harms, *Cedrela toona* var. *australis* (Roxb.) C. DC.

Other common names. toona, Australian redcedar, Burma-cedar.

Growth habit, occurrence, and use. Distributed in a natural range from India to Queensland, Australia (Francis 1951; Webb and others 1984), Australian toon—*Toona ciliata* Roemer—is the only species of *Toona* important in Hawaii and Puerto Rico. It was introduced into Hawaii from coastal rain forest areas of Australia in 1914 (Carlson and Bryan 1959; Streets 1962). Several small plantings of toon of an Indian provenance have reached sawlog size in Puerto Rico. Australian toon is a deciduous timber tree that attains heights of 30 to 43 m. It keeps its leaves longer on moist sites than on drier sites, and sometimes trees are said to be evergreen. Toon has been widely planted because the wood is valued for cabinets, furniture, decorative veneer, boats, and musical instruments (Chudnoff 1984). The red, often highly figured, wood is durable and seasons rapidly (Carlson and Bryan 1959; Francis 1951).

Flowering and fruiting. In Hawaii, Australian toon flowers from April to June. The flowers are bisexual. The 5-valved, teardrop-shaped capsules are 18 to 25 mm long (figures 1 and 2), in pendulous clusters, ripening during July to September. Seeds are disbursed during August to October (Walters 1974). Trees begin to produce seeds as early as 5 years of age, but generally do not do so with regularity or in quantity until they are 10 to 15 years old (Carlson and Bryan 1959).

Collection, extraction, and storage. The capsule turns from green to brown or reddish brown when ripe. When the first capsule in a cluster dehisces, the whole cluster should be picked. Clipping fruited branches using a pruning pole or cherry picker is recommended for seed orchards or open-grown trees. Climbing or felling will be necessary to collect capsules from mature trees in stands. The harvested fruit should be spread on trays in the sun to dry. The light

Figure 1—*Toona ciliata*, Australian toon: seed.

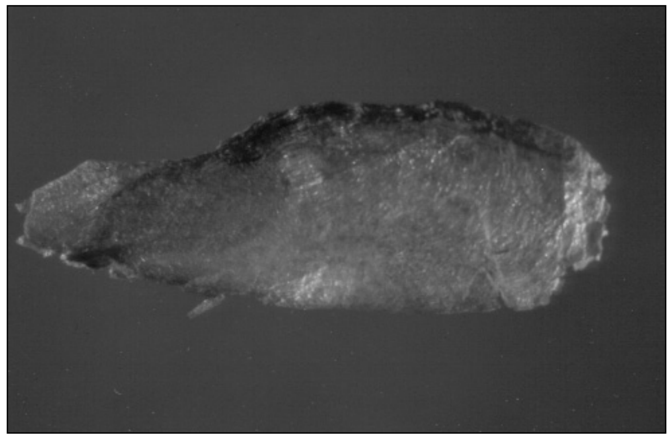
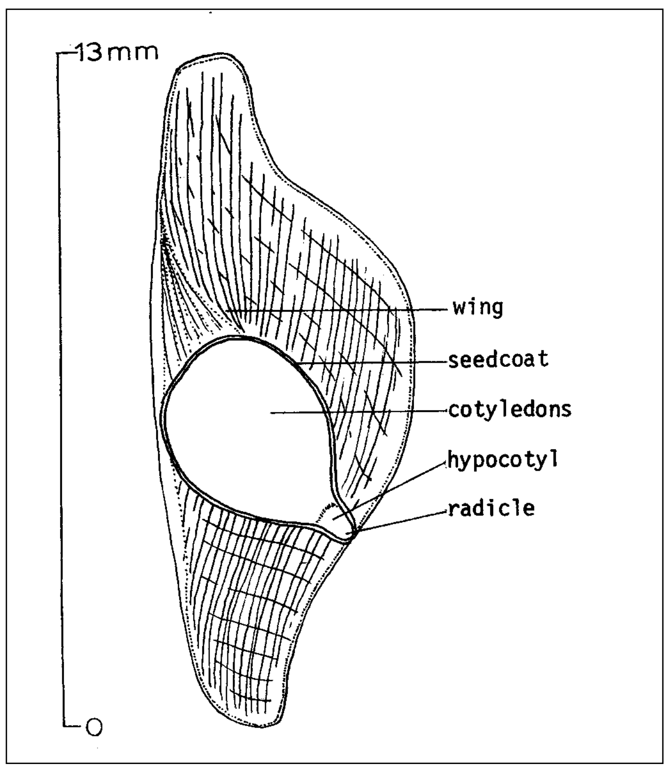


Figure 2—*Toona ciliata*, Australian toon: longitudinal section through a seed with wing attached.



brown, membranous winged seeds (figures 1 and 2) fall from the capsule as the fruit dehisces. Agitation aids the separation of seeds from the fruits. Various seed cleaners can be used to separate the seeds from chaff. Ten samples showed from 293,000 to 375,000 cleaned seeds/kg (133,000 to 174,000/lb) (Walters 1974). Seed purity was about 84% (Walters 1974). Toon seeds can be stored dry in sealed polyethylene bags at about 1 °C (Walters 1974). Even with this apparent orthodox storage behavior, however, storage life is reported to be only from 6 to 12 months (Webb and others 1984).

Germination. Australian toon seeds germinate without special treatment, but stratification for 30 days at 3 °C in plastic bags greatly increases the speed of germination. A water soak also may speed up germination (Walters 1974). Full germination of 90% of unstratified seedlots occurred in 2 weeks; full germination of 96% of stratified seedlots occurred in 1 week (Walters 1974). Another source (Webb and others 1984) cites 40 to 60% germination of fresh seeds. Germination is epigeal.

Nursery practice. Australian toon seeds can be sown in Hawaii and Puerto Rico during any month of the year, but best results in Hawaii are obtained from March to November sowings and in Puerto Rico from April and May sowings. Seeds for bareroot seedling production are broadcast into precut lines. The lines are about 12 mm deep and about 15 cm apart. Most of the seeds that fall away from the lines are put in place as the lines are covered with soil. The beds are made level to prevent washing. The soil is kept moist by frequent watering. No mulch or shade is used. Seedling density in the beds is about 160 to 270 seedlings/m^2 (15 to 25/ft^2). Seedlings are outplanted as 1+0 or $1^1/_2$+0 stock (Walters 1974). Seedlings are now more frequently grown containerized in plastic nursery bags. Seeds are germinated in germination trays or beds and transplanted to the containers after they have developed 2 or 3 leaves. Seedlings can also be planted as striplings or stumps (Webb and others 1984). Australian toon seedlings grow slowly at first and should be given shade for 2 months. Potted stock reaches plantable size in 18 to 24 months (Webb and others 1984). Attacks of the shootborer *Hypsipyla grandella* (Zeller), which usually prohibits planting *Cedrela* species in the Neotropics, are absent or unimportant in toon plantations (Viga 1976; Whitmore and Medina Gaud 1974).

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Taxaceae—Yew family

Torreya Arn.

torreya

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Growth habit, occurrence, and uses. The genus *Torreya* includes 7 species of conifer trees found in North America and eastern Asia (Little 1979; Price 1990). These species of limited distribution represent a genus that in earlier geologic times was widespread in the Northern Hemisphere—Europe, Greenland, Alaska, British Columbia, Oregon, Colorado, Virginia, and North Carolina (Abrams 1955; Boeshore and Gray 1936; Florin 1963; Schwartz and Hermann 1993a). Two species are native in the United States: Florida torreya is endemic to a small area in Florida and Georgia, and California torreya to central California (table 1). Little genetic variability has been found among populations of Florida torreya in contrast to those of California torreya (Schwartz 1993). Although growing in markedly different climates, the 2 species responded similarly in water stress tests (Schwartz and others 1995).

California torreya is a slow-growing, medium-sized tree found along streams and in canyon bottoms and other moist locations (Griffin and Critchfield 1976; Storer and Usinger 1963; Sudworth 1908). In its shrub form, it is found on serpentine soils and in chaparral. In elevation, California torreya ranges from coastal lowlands to almost 2,130 m in the southern Sierra Nevada. Under very favorable conditions, trees may grow to 23 m or more in height and 60 to 90 cm in diameter (Sudworth 1908). The tallest tree now on record is 29.3 m tall and 638 cm in circumference at 137 cm above ground (AFA 2000).

Florida torreya, also a slow-growing tree, is an endangered species found only at low elevations on ravine slopes 12 to 45 m above constant running streams on the east bank of the Apalachicola River and tributaries in Florida and Georgia and in a colony on low flat land that is 10 km west of the river (Kurz 1938; Nicholson 1990; Schwartz and Hermann 1993a&b). Florida torreya is commonly associated with seepage locations on soils ranging from coarse or fine sand to clay with limestone pebbles (Kurz 1938; USFWS 1986). In their native habitat, mature trees have reached 15 to 20 m in height and 30 to 60 cm in diameter (Harrar and Harrar 1962; Nicholson 1990; Schwartz and others 1995). However, due to severe population decline since the 1950s (the primary cause of this decline is unknown), the 1,500 or fewer immature survivors are generally less than 2 m tall (Bronaugh 1996; Schwartz and Herman 1999; Schwartz and others 1995). The tallest existing trees are found in several plantings outside of the species' endemic habitat; the largest, in North Carolina, measures 13.7 m tall and 277 cm in circumference (AFA 2000).

Because of their low availability, uses of both species of torreya are limited. Their wood is aromatic, rot-resistant, fine-grained, and excellent for cabinet-making (Burke 1975;

Table 1—*Torreya,* torreya: nomenclature and occurrence

Scientific name & synonym(s)	Common name(s)	Occurrence
***T. californica* Torr.** *T. myristica* Hook. *Tumion californicum* (Torr.) Greene	**California torreya,** California-nutmeg, stinking-yew, stinking-cedar	Central California—scattered in the Coast Ranges and on western slopes of the Cascades & Sierra Nevada
***T. taxifolia* Arn.** *Tumion taxifolium* (Arn.) Greene	**Florida torreya,** Florida-nutmeg, stinking-cedar	E bank of Apalachicola River & tributaries from Decatur Co., Georgia, to Liberty Co., Florida, & an outlying population in Jackson Co., Florida

Sources: Griffin and Critchfield (1976), Kurz (1938), Little (1979), Stalter (1990), Sudworth (1908).

Peattie 1953). Both species were used locally for such purposes as shingles, fence posts, and firewood. They grow satisfactorily outside of their native range and have received moderate use as ornamentals (Burke 1975; Sargent 1875; Wilson 1938). Fruits of California torreya were collected for food by native Californians, and the characteristics of its oil compare favorably with those of pine-nut oil for cooking purposes (Burke 1975). Squirrels have been observed eating fruits and seeds of Florida torreya and antler-rubbing scars provide evidence of use by deer (Bronaugh 1996; Nicholson 1990; Schwartz and Hermann 1993a).

Flowering and fruiting. Torreyas are dioecious. The male flowers are small, budlike, and clustered on the under sides of twigs in axils of leaves produced the previous year (Abrams 1955; Jepson 1925; Sargent 1933; Sudworth 1908). The female flowers are less numerous and occur on the lower sides of the current year's twigs. After fertilization, they develop singly into sessile, thin-fleshed arils that mature during the second season as green to purplish drupes 25 to 44 mm long (figure 1). When mature, the leathery cover eventually releases a 25- to 30-mm yellow-brown seed (Munz and Keck 1959) (figure 2). The thick woody inner seedcoat is irregularly folded into the female gametophyte, and the embryo is minute (figure 3).

Both species flower in March and April, with some flowers of Florida torreya appearing as early as January and some of California torreya extending into May (Rehder 1940; Sargent 1933; Stalter 1990; Weidner 1996). Under favorable growing conditions, Florida torreya produces male and female flowers about age 20 (Stalter 1990); in greenhouse conditions, 5-year-old sprouts produced pollen (Schwartz 1996).

Figure 1—*Torreya taxifolia*, Florida torreya: the fruit is sessile and drupe-like.

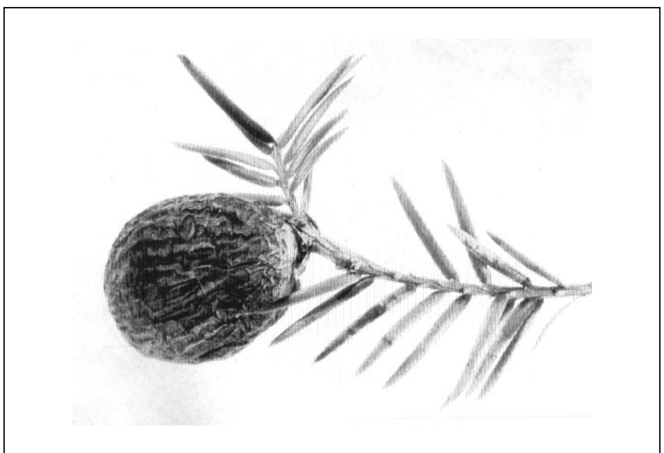


Figure 2—*Torreya*, torreya: large seeds of *T. californica*, California torreya (**left**) and *T. taxifolia*, Florida torreya (**right**).

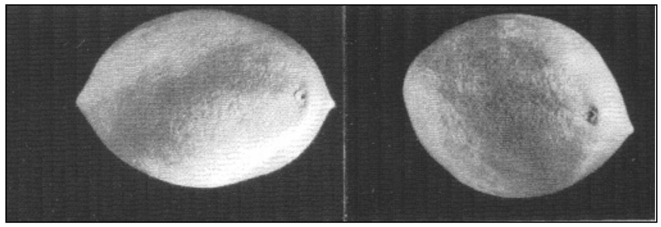
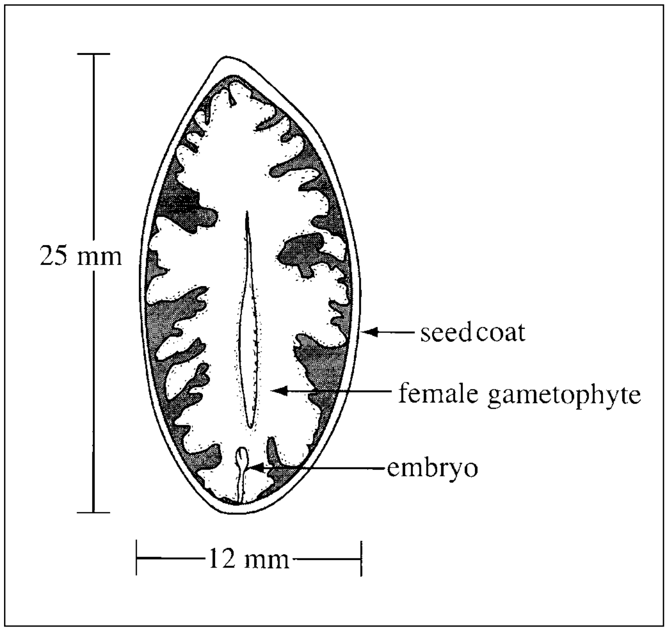


Figure 3—*Torreya californica*, California torreya: longitudinal section through a seed showing the folds of the inner seedcoat extending into the endosperm.



Information on the fruit production characteristics of both torreya species is sparse and inadequate. Fruits mature from August till November (Mirov and Kraebel 1939; Rehder 1940; Stalter 1990). At the Alfred B. Maclay Gardens in Tallahassee, Florida, fruit production from 8 trees was low and varied by tree and year. No fruits were produced in 4 years, and more than 100 fruits were available in 1985, 1986, 1987, and 1989 (Weidner 1996).

Collection, extraction and storage. Collection of Florida torreya fruits from the endemic population is not possible now because there are only scattered sexually mature male trees and no mature females (Bronaugh 1996; Schwartz and Hermann 1993a; Schwartz 1996). Trees in cultivation include less than 2 dozen reproductive females (Bronaugh 1996), so extraordinary diligence is required to collect any seeds that are produced. Fruits have been picked slightly green to gather them before the squirrels do and then held in open storage until the outer cover turned dark; then the pulp was softened in water and removed by rubbing fruits against hardware cloth (Weidner 1996).

Fruit production of California torreya is common and widespread enough to forestall concerns about shortage; several hundred pounds may be collected in single commercial collections (Callahan 1996). The fruits are generally picked from the trees but are sometimes collected after they have been shed. Seed extraction is about the same as for Florida torreya, with the softened pulp removed by water pressure and some hand rubbing (Callahan 1996). Care is needed to avoid damage to the relatively tender seedcoat. Seed quality of California torreya is generally good and can be improved sometimes by separating light seeds through flotation.

Storage experience is short-term and fragmentary because torreya seeds are generally used as available. Based on incidental observations, the seeds may be recalcitrant, as high moisture content appears necessary to maintain their viability. California torreya has been stored in moist vermiculite or sphagnum moss at 2 to 7 °C for up to 3 years (Callahan 1996). Some seeds of both species will germinate in lengthy cool or warm stratification (Callahan 1996; Weidner 1996).

Seeds of California torreya averaged 324/kg (147/lb), with a range of 243 to 421/kg (110 to 191/lb) in 3 samples (Roy 1974). Florida torreya had 496 seeds/kg (225/lb) in 1 sample at a moisture content of 8.6% (Roy 1974).

Pregermination treatments and germination tests. Standard germination test procedures have not been developed yet for torreya seeds. Both species require lengthy after-ripening and stratification, but efforts made to date have not identified methods for timely germination testing of fresh or stored seeds.

As available, fresh seeds of Florida torreya have been tested at Alfred B. Maclay State Gardens according to the 9 variations of methodology specified in the recovery plan for the species (USFWS 1986). Warm stratification in a half and half mixture of Canadian peat and coarse sand for 6 months in a greenhouse at 13 to 18 °C has produced the best results. Gentle cracking of the distal end of the seedcoat before warm stratification produced somewhat higher germination than a preliminary 20-minute soak in 10% chlorine bleach or stratification alone (table 2) (Weidner 1996).

Germination averaged lowest for sowings made directly into outdoor beds. The germination results indicate that seedcrop quality or other factors differed from year to year, and results were also not very consistent for the same pretreatment and germination sequence.

Procedures have been prescribed for determining viability of torreya seeds quickly by a tetrazolium (TZ) test on excised embryos (Moore 1985). Seed preparation involves puncturing the seedcoat, soaking the seeds in water for 18 hours, and then cutting them open to expose nutritive tissue and the distal end of the embryo. The prepared seeds are soaked in a 1% TZ solution for 24 to 48 hours, depending on temperature; nutritive tissue and embryo are then further exposed and evaluated. Viable seeds have a completely stained embryo and nutritive tissue.

Nursery practices. Torreya germination is hypogeal. Both California and Florida torreyas can be reproduced from seeds but quantities grown are so small and infrequent that nursery practices are underdeveloped.

The protocols specified in the recovery plan (USFWS 1986) and the germination resulting therefrom (table 2) are evidently the most recent, systematic, and successful attempts to produce Florida torreya seedlings for outplanting. Seedlings are slow growing and very susceptible to damping-off, so repeated fungicide drenches are necessary.

Seeds of California torreya sown untreated in the fall will germinate late the next summer or in the second spring. Germination can be obtained by April of the first season by sowing in the fall and keeping the seedbed at 7 to 10 °C (Callahan 1996). Seeds generally have high viability—90 to

Table 2—*Torreya,* torreya: germination of *T. taxifolia* seeds

	Germination by seed year			
Pre-germination treatment*	**1985**	**1990**	**1993**	**Average**
6 months of warm stratification	69	13	80	54.0
Bleach + 6 months of warm stratification	77	0	85	54.0
Cracking + 6 months of warm stratification	100	25	86	70.3
3 mon of warm, then 3 months of cold stratification	85	38	58	60.3
Bleach + 3 months of warm, then 3 months of cold stratification	77	25	44	48.7
Cracking + 3 months of warm, then 3 months of cold stratification	62	38	35	45.0

Source: Weidner (1996).

98% germination. In a test of seeds stratified for 3 months, 92% germinated in 232 days after sowing (Mirov and Kraebel 1939). Two growing seasons are required to produce seedlings 15 to 25 cm tall (Callahan 1996; Wilson 1996).

Both species sprout from stumps or root crowns and can be propagated vegetatively. Metcalf (1959) described sprouting of California torreya as vigorous—"like redwood." Stalter (1990), Godfrey (1988), and others indicated that the current endemic Florida torreya population probably originated largely from vegetative propagation, but Schwartz and Hermann (1993a) concluded that most originated from seeds.

The urgency of conserving Florida torreya has stimulated development of its reproduction by cuttings (Bailo and others 1998; Nicholson 1988, 1993). Up to 91% of cuttings collected in November from trees throughout the species' native range rooted in a mixture of pumice, peat, and perlite mixture. The cuttings were potted and grown for 2 years and then shipped to botanic gardens and research institutions. A database on living Florida torreya material is maintained by The Center for Plant Conservation, headquartered at the Missouri Botanical Garden, St. Louis, Missouri.

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Anacardiaceae—Sumac family

Rhus L.

sumac

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Growth habit, occurrence, and use. The genus sumac—*Rhus* L.—consists of about 150 species of deciduous or evergreen shrubs, trees, and vines indigenous to temperate and subtropical regions of both hemispheres (LHBH 1976; Rehder 1990; RHS 1994). They occur frequently as pioneer species on disturbed sites and abandoned fields and along woodland borders. However, they are intolerant of shade and cannot compete with invading trees (Gill and Healy 1974). Sumacs are tolerant of poor, sandy, or rocky soils, and of soil moisture regimes ranging from dry to wet. For example, smooth sumac is adaptable to sites ranging from nearly bare rock to sand to heavy clay, and tolerates soil pH from acidic to slightly alkaline (Johnson and others 1966). Species native to North America are listed in table 1.

Three species of the genus *Toxicodendron*—poison-oak, *Toxicodendron diversilobum* (Torr. & Gray) Greene; poison-ivy, *T. radicans* (L.) Kuntze; and poison-sumac, *T. vernix* (L.) Kuntze—also are included because they are referred to frequently as *R. diversiloba* Torr. & Gray, *R. radicans* L., and *R. vernix* L., respectively. Laurel-sumac—*Malosma laurina* (Nutt.) Nutt. ex Abrams), until recently known as *Rhus laurina* Nutt.—is also included for the same reason.

Members of the sumac genus are shrubs, vines, or trees with alternate, simple, or featherlike (pinnate) compound leaves. Winter buds are minute, naked (without scales), and covered with dense hairs. Sumacs are fast growing and usually short-lived plants. Roots of sumac can spread more than 16 m in each direction, forming an extensive root network near the surface (Duncan 1935).

Sumacs are valuable for erosion control because of proliferation of rhizomes that results in an extensive root system. The species is ideally suited for roadside plantings, revegetation of areas of eroded or depleted soils, range reclamation and mine spoils restoration, and other conservation plantings (Brinkman 1974; Humphrey 1983). Some are grown as ornamentals for their pinnate foliage; persistent terminal showy fruits; and brilliant red, orange, or yellow fall color. This is especially true of the cutleaf staghorn sumac —*R. hirta* (L.) Sudworth 'Laciniata'— with its deeply cut, bright green leaves in summer; brilliant orange-red fall color; and twisted, exotic forms in winter (Cross 1988). Sumacs are recommended as ornamental shrubs for dry and open sites, but cultivation is easy in any garden soil.

Species of sumac also provide wildlife with habitat and an important source of food. Their thicket-forming growth provides excellent cover for birds and animals. The fruits, produced in large quantities each year, are eaten by over 30 species of birds, as well as rodents and other mammals. The twigs and leaves are browsed by deer (*Odocoileus* spp.), moose (*Alces americana*), and mountain sheep (*Ovis* spp.) (Elias 1989; Strauss 1988). The wood is soft, weak, and of no commercial value (Elias 1989). However, skunkbush was once used by Native Americans for food, as a tobacco substitute, and for making baskets. In addition, some species can be processed to yield tannin and lacquer (LHBH 1976).

Geographic races and hybrids. There is some disagreement among taxonomists as to the classification of genera (*Rhus* vs. *Toxicodendron*) and particular species. For example, prairie sumac is often considered to be a variety or race of shining sumac (Elias 1989). In addition, natural hybridization occurs in the wild (Johnson and others 1966).

Flowering and fruiting. Plants are dioecious (flowers imperfect, one sex) or polygamous (flowers imperfect and perfect, both sexes). Flowers are small and rather inconspicuous and are borne in terminal or axillary clusters in the spring (table 2). They are pollinated by bees. Fruits are small, hairy, berry-like drupes, rounded to egg-shaped, containing a single nutlet or seed without endosperm (figures 1–3) (Brinkman 1974; Elias 1989). In most species, fruits form a dense cluster and ripen in the fall and may persist on the plant through winter. Seeds are spread primarily by birds and small mammals (Brinkman 1974). Sumacs generally produce copious quantities of seeds with some seeds produced nearly every year.

Table 1—*Rhus,* sumac; *Toxicodendron,* poison-ivy, etc.; *Malosma,* laurel-sumac: nomenclature and occurrence

Scientific names & synonym(s)	Common name(s)	Occurrence
R. aromatica **Ait.** *R. canadensis* Marsh.	**fragrant sumac,** lemon sumac, sweet-scented sumac	Vermont & Ontario to Minnesota, S to Florida & Louisiana
R. choriophyllum **Woot. & Standl.**	**Mearns sumac**	S New Mexico & Arizona & adjacent Mexico
R. copallina **L.**	**shining sumac,** winged sumac, mountain sumac, wing-rib sumac, dwarf sumac	Maine & Ontario to Minnesota, S to Florida & Texas
R. glabra **L.** *Schmaltzia glabra* Small *R. borealis* Greene	**smooth sumac,** scarlet sumac	Maine to British Columbia, S to Florida & Arizona
R. hirta **(L.) Sudworth** *R. typhina* L.	**staghorn sumac,** velvet sumac	Quebec to Ontario, S to Georgia, Indiana, & Iowa
R. integrifolia **(Nutt.) Benth. & Hook. f. ex Brewer & S. Wats**.	**lemonade sumac,** sourberry, lemonade berry	S California & Baja Californa
R. kearneyi **Barkl.**	**Kearney sumac**	Arizona & N Baja California
R. lanceolata **(Gray) Britt.** *R. copallina* var. *lanceolata* Gray	**prairie sumac**	S Oklahoma & E Texas to S New Mexico & adjacent Mexico
R. michauxii **Sarg.** *Schmaltzia michauxii* M. Small	**false poison sumac**	North Carolina to Georgia
R. microphylla **Engelm. ex Gray**	**desert sumac,** scrub sumac, small-leaf sumac	SW US & adjacent Mexico
R. ovata **S. Wats.** *R. ovata* var. *traskiae* Barkl.	**sugarbush,** sugar sumac	Arizona, S California, N Baja California
R. trilobata **Nutt.** *Schmaltzia anisophylla* Greene *S. trilobata* var. *anisophylla* (Greene) Barkl.	**skunkbush,** ill-scented sumac	Illinois to Washington, California, & Texas
R. virens **Lindheimer ex Gray**	**evergreen sumac,** tobacco sumac, lentisco	SW US
RELATED TAXA		
Toxicodendron diversilobum **(Torr. & Gray) Greene** *R. diversiloba* Torr. & Gray *R. toxicodendron* ssp. *diversilobum* Torr. & A. Gray) Engl.	**poison-oak**	British Columbia to Baja California
T. radicans **ssp.** ***radicans*** **(L.) Kuntze** *R. radicans* L.; *R. toxicodendron* L.	**poison-ivy**	Nova Scotia to Florida, W to Minnesota, Nebraska, & Arkansas
T. vernix **(L.) Kuntze** *R. vernix* L.	**poison-sumac,** swamp sumac, poison elder	Swamps, Maine to Minnesota, S to Florida & Louisiana
Malosma laurina **(Nutt.) Nutt. ex Abrams** *R. laurina* Nutt.	**laurel-sumac**	S California, Baja California

Sources: Elias (1989), LHBH (1976), Rehder (1990), RHS (1994).

Collection of fruits, seed extraction, and cleaning. Fruit clusters, which may be picked by hand as soon as they are ripe, are often available until late in the year. If collected early, fruits of smooth sumac and staghorn sumac, which occur in very dense clusters, may need additional drying and should be spread out in shallow layers for drying. However, fruits usually will be dry enough to process if they are collected in late fall or early winter (Brinkman 1974). Hybrid clumps often are found where smooth sumac and staghorn sumac occur near each other (Johnson and others 1966). These hybrid clumps may have seed-stalk heads that appear normal, but most seeds therein are generally empty, with the few full seeds usually infertile. Care must be taken to avoid such hybrid clumps. Even seeds of nonhybrid clumps should be checked carefully before collection to make certain that an excessive amount of empty seeds are not present. An estimate of the amount of empty seeds can be determined by crushing a small sample with a pair of pliers (Johnson and others 1966).

Dried fruit clusters can be separated into individual fruits by rubbing or beating the clusters in canvas sacks, followed by screening to remove debris (Brinkman 1974). Seeds can then be cleaned by running them through a macerator with water to remove remaining pieces of seedcoats

Table 2—*Rhus,* sumac; *Toxicodendron,* poison ivy, etc.; *Malosma,* laurel-sumac: growth habit, flowers, and fruits

Speicies	Growth habit & max height	Flowers	Fruits
R. aromatica	Shrub to 2.5 m	Yellowish, in clustered spikes 5–20 cm long, forming short panicles that appear before leaves	Red, hairy, 6 mm across; early summer, persist into early winter
R. choriophylla	Shrub or small tree to 5 m with an open irregular crown	Tiny, in dense branched clusters 5–6 cm long & wide from July–August	Red, hairy, 6-8 mm across
R. copallina	Shrub or small tree to 6 m	Greenish, in dense terminal panicles	Red, hairy; late summer, persist into winter
R. glabra	Shrub or tree to 6 m	Green, in dense panicles 10–25 cm long	Scarlet, hairy; summer
R. hirta	Shrub or tree to 9 m, twigs densely pubescent	Greenish in dense, terminal panicles 10–20 cm long	Crimson, densely hairy; late summer, persist on plant into winter
R. integrifolia	Evergreen shrub or tree to 9 m	White or pinkish in pubescent panicles	Dark red, hairy; spring
R. kearneyi	Large shrub or tree to 5 m	White in short, crowded clusters at tips of branchlets	Reddish, hairy
R. lanceolata	Thicket-forming shrub or small tree to 10 m	Yellowish-green to white in dense clusters at end of branchlets in July or August	Dark red, hairy; September or October
R. michauxii	Low stoloniferous shrub to 1 m	Greenish-yellow in panicles 10–20 cm long	Scarlet, densely hairy, in dense panicles
R. microphylla	Shrub, to 2 m, rarely treelike to 5 m	White in heads or spikes	Globose, to 0.1 cm diameter, orange-red
R. ovata	Evergreen shrub to 3 m, rarely a tree to 4.5 m	Light yellow, in short dense spikes	Dark red, hairy; spring
R. trilobata	Shrub to 2 m	Greenish, in clustered spikes, appearing before leaves	Red, hairy; spring
R. virens	Shrub	White to 4 cm long in terminal panicles	—
Related Taxa			
T. diversilobum	Shrub to 2.5 m, sometimes climbing	Greenish, in axillary panicles	Whitish
T. radicans ssp. *radicans*	Trailing or climbing vine, shrub, or rarely a tree	Greenish white in panicles 3–6 cm long	Whitish, berrylike 5–6 mm across, in axillary clusters; early summer, persisting into winter
T. vernix	Shrub or small tree to 9 m	Greenish, in slender panicles 8–20 cm long	Greenish white in pendent axillary panicles to 20 cm long; pedicles persist through winter
M. laurina	Shrub, 3–6 m	Greenish white, in dense panicles 5–10 cm long	Whitish; early summer

Sources: Elias (1989), LHBH (1976), Rehder (1990), RHS (1994).

and empty seeds. Such thorough cleaning is seldom practiced except for skunkbush; seeds of other species are sown with pieces of the fruit wall still attached (Brinkman 1974). Trials have shown that about 99% of the empty seeds of smooth sumac can be removed by flotation, as empty seeds float and filled ones sink (Johnson and others 1966). However, the flotation method of separating empty seeds is not always successful with seeds of staghorn sumac (Brinkman 1974). Number of seeds per unit weight and seed yields vary among species (table 3).

Storage. Seeds of sumac are orthodox in storage behavior and can be stored over winter and possibly for years without special treatment (Dirr and Heuser 1987). Seeds of smooth sumac stored at room temperature for 10 years still exhibited over 60% germination, suggesting that controlled storage conditions are not required. Seeds of shining sumac have even survived 5 years of burial in the soil in Louisiana (Haywood 1994). However, Farmer and others (1982) recommend storing dried seeds of smooth sumac and shining sumac in sealed glass containers at 3 °C. Seeds of other species should be stored under a temperature range from 0 to 5 °C.

Pregermination treatments. Seeds of sumac need to be scarified in concentrated sulfuric acid for 1 to 6 hours, depending upon the species—then either fall-planted out-of-doors or stratified for approximately 2 months at about 4 °C before planting (Hartmann and others 2002). Farmer and others (1982) reported that without scarification, < 5%

Figure 1—*Rhus,* sumac: fruits of *R. triblobata,* skunkbush (**left**) and *R. hirta,* staghorn sumac (**right**).

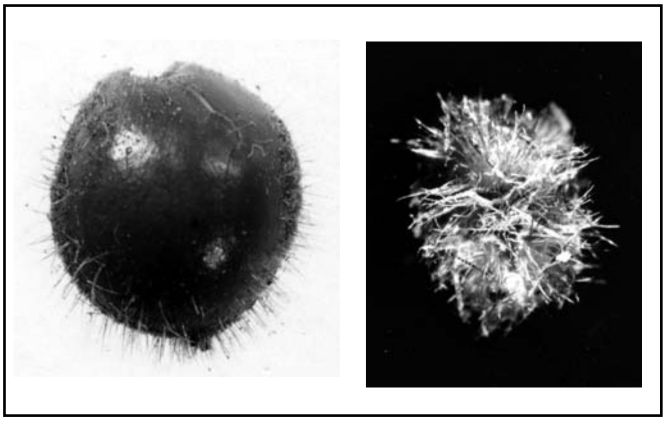


Figure 2—*Rhus,* sumac; *Malosma,* laurel-sumac: nutlets (seeds) of *R. glabra*, smooth sumac (**upper left**); *R. integrifolia,* lemonade sumac (**upper right**); *M. laurina*, laurel-sumac (**middle left**); *R. ovata*, sugarbush (**middle right**); *R. triblobata,* skunkbush (**bottom left**); *R. hirta*, staghorn sumac (**bottom right**).

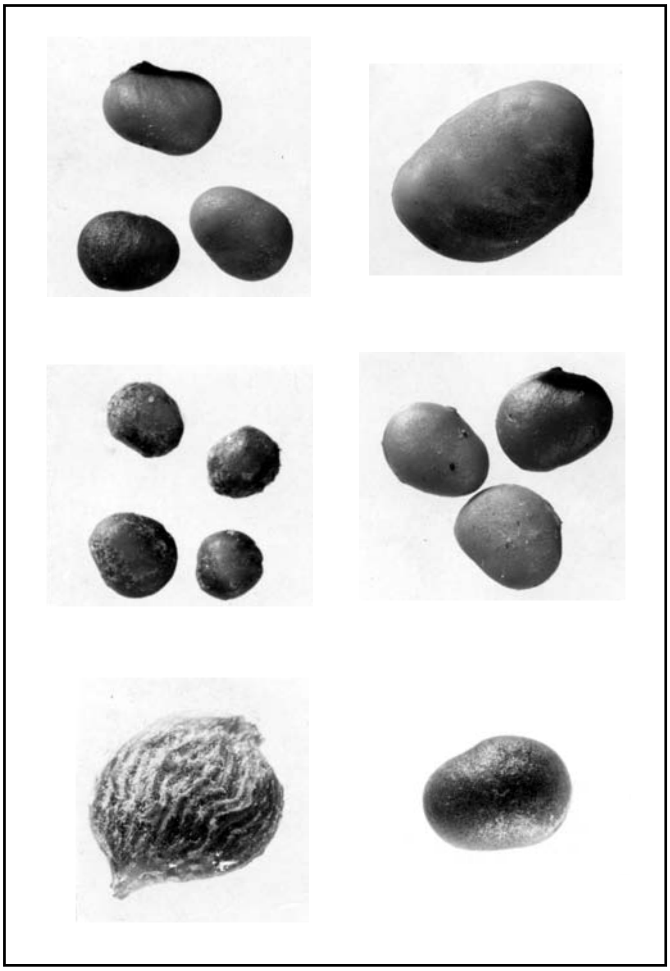
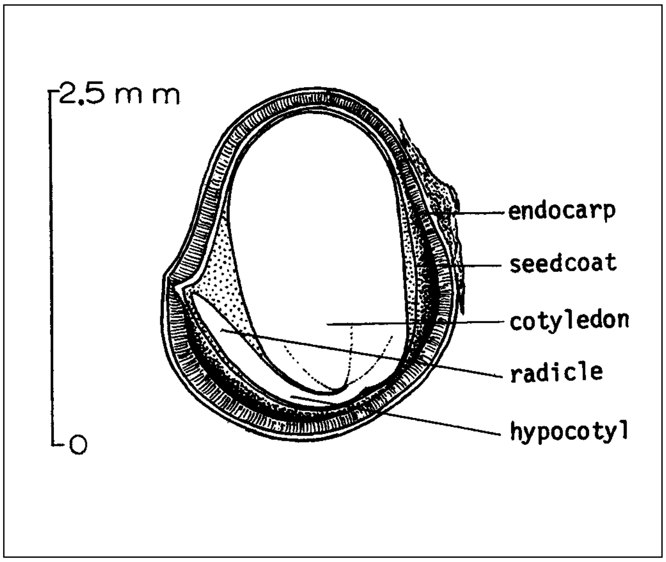


Figure 3—*Rhus hirta*, staghorn sumac: longitudinal section of a seed.



of seeds of smooth sumac germinated, but 3 to 4 hours of scarification in concentrated sulfuric acid promoted an average of 58% germination. Even after 20 years, without scarification, 3% of the seeds receiving no acid treatment germinated. However, there was a gradual increase in the number of decayed seeds with increasing durations of scarification (Farmer and others 1982).

In other species such as fragrant sumac and skunkbush, seed dormancy is caused by both a hard seedcoat and a dormant embryo, thus requiring both scarification and stratification for optimum germination (Heit 1967). These 2 treatments must be performed in proper sequence for spring-sown seeds, but the moist prechilling treatment is not necessary for fall-sown seeds. Scarification with sulfuric acid for about 1 hour followed by cold stratification at 1 to 4 °C for 1 to 3 months is recommended for seeds of fragrant sumac. Skunkbush requires 1.5 to 2 hours of scarification and 1 month or slightly longer of moist prechilling for maximum germination (Heit 1967; Weber and others 1982). Seeds of evergreen sumac need to be acid-scarified with concentrated sulfuric acid for 50 minutes and then cold-stratified for 73 days (Hubbard 1986; Tipton 1992).

High temperatures also are effective in removing seedcoat dormancy, a phenomenon that occurs naturally during wildfires. Germination of prairie sumac increases after seeds are exposed to fire (Rasmussen and Wright 1988). High temperatures scarified seeds of prairie sumac when temperatures reached 76 °C in wet environments or 82 °C in dry environments. Heat ruptures the seedcoats and waxy cuticle, enabling seeds to imbibe water. Heat generated on or near the soil surface by fire (82 °C) is sufficient to scarify seeds

Table 3—*Rhus,* sumac; *Malosma,* laurel-sumac: seed yield data

	Fruits (x1,000)/wt		Cleaned seeds (x1,000)/weight				
			Range		Average		
Species	/kg	/lb	/kg	/lb	/kg	/lb	Samples
R. copallina	—	—	81.4–173.8	37.0–79.0	125.4	57.0	4
R. glabra	50.6–105.6	23.0–48.0	52.8–277.2	24.0–126.0	107.8	49.0	28
R. hirta	66.0	30.0	107.1–148.7	48.7–67.6	117.3	53.3	5
R. integrifolia	6.6	3.0	15.0–17.6	6.8–8.0	16.7	7.6	2
R. ovata	37.4	17.0	41.1–57.2	18.7–26.0	—	—	2
R. trilobata	15.4–19.8	7.0–9.0	23.3–66.0	10.6–30.0	44.7	20.3	9
M. laurina	198.0	90.0	—	—	285.1	129.6	1

Source: Brinkman (1974).

(Rasmussen and Wright 1988). In seeds of nutgall tree, or Chinese gall, or nutgall tree—*R. chinensis* Mill., a species native to China that is often referred to incorrectly as *R. javanica* L.—a temperature of 55 ± 7.4 °C was successful in overcoming the impermeable seedcoat (Washitani 1988). With increasing temperature, shorter exposures became sufficient to render seeds permeable, but temperatures > 75 °C damaged seeds and resulted in lower germination. The most favorable regimes among those tested were temperatures of 65 to 75 °C for durations of 30 to 120 minutes, which frequently occur on denuded ground during the midday hours of clear spring and summer days (Washitani 1988).

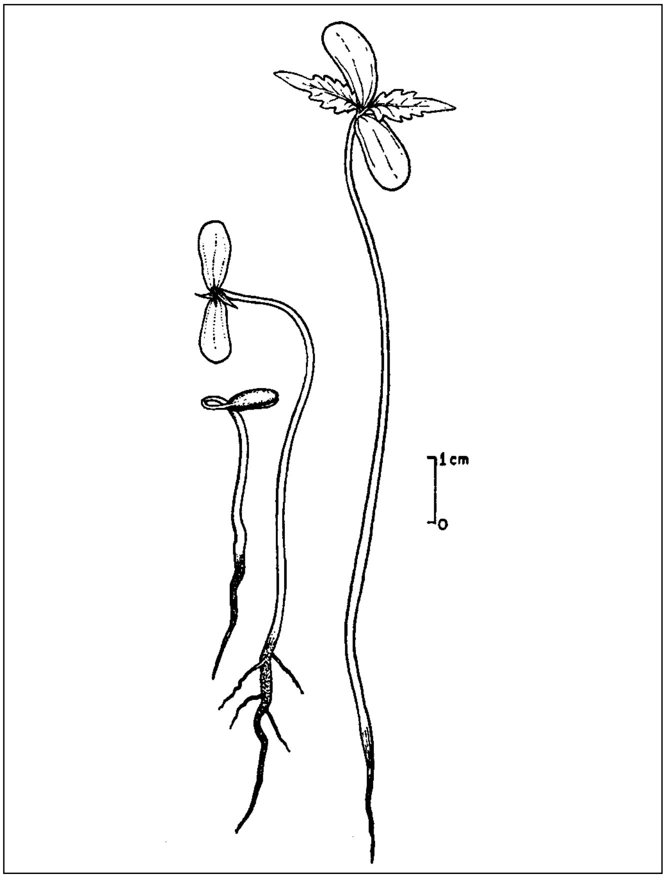
Other scarification treatments include hot water and mechanical scarification. A 2-minute submersion in boiling water was the most effective of timed heat treatments for seeds of smooth sumac (Johnson and others 1966). Germination of seeds of prairie sumac scarified with sulfuric acid was greatest when they were soaked for 60 minutes but was less than that of seeds that were mechanically scarified or treated with wet heat at 94 or 97 °C (Rasmussen and Wright 1988).

The degree of seedcoat hardness and embryo dormancy varies within and among seedlots for most species (Hartmann and others 2002; Krugman and others 1974). Seed sources also must be considered when determining scarification and stratification pretreatments. This is true for sumacs, as individual seedlots and seed sources vary in their acid treatment requirements to remove seedcoat dormancy (Heit 1967). Test averages alone are not a good representation of germination potential because of wide family differences and a significant family by treatment interaction (Farmer and others 1982). For example, germination of individual clonal seedlots of smooth sumac ranged from 25 to 75% (Farmer and others 1982). Family differences in germination are apparently based on variable susceptibility of individual seeds to scarification (Farmer and others 1982). The duration of scarification and stratification should be determined for each seedlot.

Germination tests. Light and temperature influence germination, which is epigeal (figure 4). When seeds were subjected to total darkness, the percentage germination of seedlots of smooth sumac (Brinkman 1974) and prairie sumac (Rasmussen and Wright 1988) were reduced. Heit (1967) also stressed the importance of germination in the presence of light. Likewise, temperature also is important. Evergreen sumac germinated at temperatures ranging from 21 to 30 °C (Tipton 1992), similar to that reported for other sumacs (Brinkman 1974). Final percentage germination declined with increasing temperature from a predicted maximum of 52% at 21 °C, whereas maximum germination rate increased with temperature to a predicted maximum of 69% germination at 31 °C. These results demonstrate that under low temperatures, germination would be delayed and slow, but eventually yield more seedlings. Under high temperatures, germination would also be delayed, but relatively rapid, yet it would yield few seedlings (Tipton 1992). In studies with alternating day/night temperatures, percentage germination of smooth sumac and shining sumac seedlots was significantly greater when they were subjected to an alternating temperature (16/8 hours) of 20/10 °C than at 15/5 °C or 30/20 °C. Germination rate was also affected—germination was completed within 10 days at 20/10 °C and 30/20 °C but took 20 days at 15/5 °C (Farmer and others 1982). Maximum germination of prairie sumac occurred when seeds were subjected to alternating temperatures of 20/10 °C with a short-day light cycle of 8 hours of light and 16 hours of darkness (Rasmussen and Wright 1988).

Gibberellins and ethylene or ethephon (2-chloroethyl phosphonic acid) are known to overcome dormancy in seeds of some species by completely or partially substituting for the moist-prechilling requirement (Hartmann and others 2002; Norton 1985). This was true for seeds of staghorn sumac, as germination after 30 days was higher for seeds

Figure 4—*Rhus hirta*, staghorn sumac: seedling development at 2, 4, and 17 days after germination.



incubated for 24 hours in 100 mg/liter gibberellic acid (GA) (26% germination) than 0, 1, 10, or 1000 mg/liter GA (19, 22, 24, and 22% germination, respectively). When seeds were stratified at 4 °C for 0, 10, 20, or 30 days, percentage germination increased with the length of the stratification period to a maximum of 48%. However, combining infusion of GA into seeds with cold stratification did not further enhance germination if the stratification period exceeded 10 days (Norton 1986, 1987). In contrast, promotion of germination due to ethephon was demonstrated only after 20 or 30 days of stratification, whereas no effect was observed in the absence of a cold treatment (Norton 1985). A combination of ethephon treatment at 200 mg/liter for 24 hours followed by 30 days of cold treatment at 4 °C increased germination to 60%.

Soil pH has some influence on germination. Once prairie sumac seeds were scarified, germination occurred under a wide range of pH (4 to 10), but highest germination occurred at a pH of 10 (Rasmussen and Wright 1988). In nature, soil pH increases for a short time following fire. Increased pH is attributed to ash deposition on burned areas. Fire enhances these conditions, thus aiding establishment following burning. Furthermore, seedling emergence and root growth of staghorn sumac were inhibited by simulated acid rain (Lee and Weber 1979), which tended to lower soil pH.

In addition, exudates from leaves of sumac (identified as miasmins and saprolins) inhibit germination and seedling growth of a number of other plants (Matveev and others 1975). Water-soluble extracts from leaves of shining sumac had an adverse effect on germination and radicle growth of loblolly pine—*Pinus taeda* L.—which suggests that shining sumac, a common shrub on southern pine sites, may interfere with regeneration of loblolly pine from seeds (Smith 1990). Furthermore, extracts from seeds of skunkbush inhibited growth of brome—*Bromus* L. spp.—either by killing newly germinated seeds or by reducing coleoptile growth by 30% compared to the control (Hampton and Singh 1979).

Nursery practice and seedling care. Sumacs can be propagated from seeds, by rooting stem cuttings (Hartmann and others 2002; Tipton 1990), or by field-planting root cuttings in early spring (Cross 1982, 1988; Jonsson and Zak 1975; Hartmann and others 2002). Although sumacs are heavy seed producers, commercially they are usually propagated vegetatively by root cuttings (Cross 1988; Jonsson and Zak 1975).

When propagating by seeds, the ideal sowing time depends on the species. Seeds that do not require stratification, such as those of shining, smooth, and staghorn sumacs, are sown best in the spring after a scarification treatment. Seeds scarified in sulfuric acid should be rinsed thoroughly with running water prior to sowing. Species that exhibit double dormancy, such as fragrant and skunkbush, can be either subjected to scarification and stratification and planted in spring or they can be scarified and sown in the fall, thus allowing winter temperatures to provide moist prechilling naturally (Dirr and Heuser 1987). In general, seeds should be sown at least 1.3 linear cm (1/2 in) deep at a rate of about 82 viable seeds/linear m (25/ft) (Brinkman 1974). However, depth of planting from 0 to 6 cm (0 to 2.4 in) did not affect percentage emergence of seeds of prairie sumac (Rasmussen and Wright 1988).

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Euphorbiaceae—Spurge family

Triadica sebiferum (L.) Small

tallowtree

Franklin T. Bonner

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Synonym. *Sapium sebifera* (L.) Roxb.

Other common name. Chinese tallowtree.

Growth habit, occurrence, and use. Tallowtree—*Triadica sebiferum* (L.) Small—is a small deciduous tree that attains heights of about 10 m at maturity. A native of China, the species has been widely planted in the coastal plain from South Carolina and Florida to Texas, Oklahoma, and Arkansas. The bright red fall foliage makes the tree a popular ornamental, and the seeds have some value as wildlife food. In Asia, oils are extracted from the seeds and waxes from the seedcoats for use in a wide variety of products, including diesel fuel additives, soaps, candles, and cloth dressings (Bringi 1988; Samson and others 1985; Singh and others 1993; Vines 1960). Tallowtree readily escapes from cultivation and is common along roadsides of the Gulf Coast, where many consider it a pest species.

Flowering and fruiting. Both pistillate and staminate flowers are borne on the same yellowish green spike in the spring. The fruit, ripening in October to November, is a rounded, 3-lobed capsule, 8 to 13 mm in diameter (Vines 1960). Its greenish color changes to a brownish purple at maturity (Bonner 1974). There are 1 to 3 white waxy seeds per capsule (figures 1 and 2). In India, this species bears fruit as early as the third year after planting, and mature trees can yield 20 to 25 kg (Singh and others 1993).

Collection, cleaning, and storage of seeds. The dry capsules can be collected from the trees by hand after dehiscence (fruit-splitting) has started. Seeds can be removed from the capsules by gentle flailing in burlap bags or by being run through macerators at slow speeds. On a sample of capsules from a tree in central Mississippi, the following data were obtained (Bonner 1974):

Capsules per volume	30,300/hl (10,700/bu)
Seeds per weight	6,100/kg (2,780/lb)
Moisture content of seeds (% of fresh weight)	6
Sound seeds (% of total seeds)	90

Figure 1—*Triadica sebiferum*, tallowtree: seed.

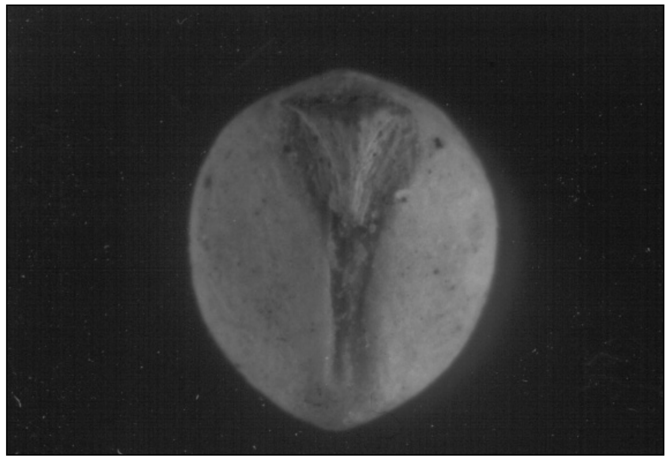
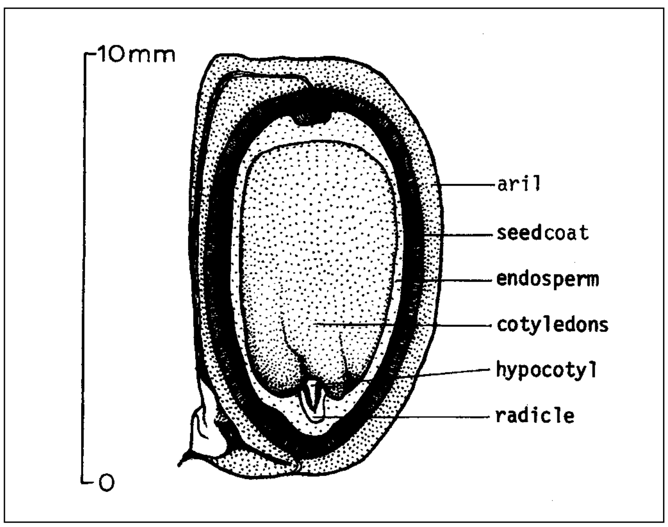


Figure 2—*Triadica sebiferum,* tallowtree: longitudinal section through a seed.



There are no known storage tests with seeds of tallow tree, but drying the sample noted above to 6% without killing the seeds indicates that they are orthodox in storage behavior. Short-term storage at low temperatures and seed moisture contents should be no problem. The seeds have a lipid content of about 20% (Zubair and others 1978), how-

T

ever, so sub-freezing temperatures should be used for any storage over 5 years.

Germination tests. Seeds of tallowtree are not dormant and do not typically require pretreatment. Germination results of 60 to 62% in germination beds have been reported from India (Singh and others 1993). Fresh seeds from the Mississippi collection had a laboratory germination of 38% after 30 days on moist Kimpak at day-night temperatures of 30 and 20 °C. The seeds received 8 hours of light during the day temperature. Moist stratification at 2 °C for 34 days increased the rate of germination but did not boost the percentage. Sixty days of stratification apparently induced a deep secondary dormancy (Bonner 1974). Tallowtree can also be propagated by cuttings from root suckers (Singh and others 1993).

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Myrtaceae—Myrtle family

Lophostemon confertus (R. Br.) P.G. Wilson & Waterhouse

brushbox

Edwin Q. P. Petteys and Franklin T. Bonner

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Synonyms. *Lophostemon australe* Schott., *Tristania conferta* R. Br., *T. subverticillata* Wendl.

Other common names. Brisbane-box, scrub-box, vinegar-tree.

Growth habit, occurrence, and uses. Brushbox is a straight-boled evergreen tree that obtains heights of 35 to 45 m (18 m in Hawaii) (Carlson and Bryan 1959; Francis 1951; Maiden 1904). It is native to the eastern coastal region of Australia and has become naturalized throughout India and Africa as well as in California, Florida, and Hawaii (Bailey 1906; Little and Skolmen 1989; Streets 1962). It has been planted for timber and for ornamental purposes in Hawaii (Little and Skolmen 1989). The wood grown in Hawaii is moderately resistant to decay and termites, whereas wood grown in Australia is considered to be very resistant to both. In Hawaii, the wood is used for pallets, flooring, and pulp chips, whereas in other regions it is used extensively for construction, shipbuilding, bridges, railway crossties, and pallets (Little and Skolmen 1989). This species is a hardy ornamental and shade tree with handsome foliage (Streets 1962)

Flowering and fruiting. The white brushbox flowers appear in clusters of 3 to 7 on short branches at leaf bases and the backs of leaves. Individual flowers are about 2.5 cm wide. The fruits are bell-shaped capsules 1 to 1.5 cm in diameter and light green to brown in color (Little and Skolmen 1989; Neal 1965). Individual seeds are flat, elongated (figure 1), light brown in color, and less than 4 mm long (figure 2). Seeds are produced moderately well at 15 to 20 years of age (Carlson and Bryan 1959). In Hawaii, trees can be found in all stages of the reproductive cycle at any time during the year, depending on the aspect and elevation at which they are growing (Petteys 1974).

Figure 1—*Lophostemon confertus*, brushbox: seed.

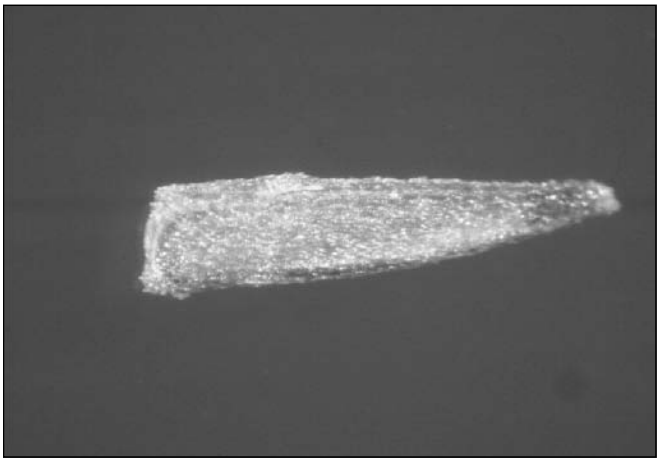
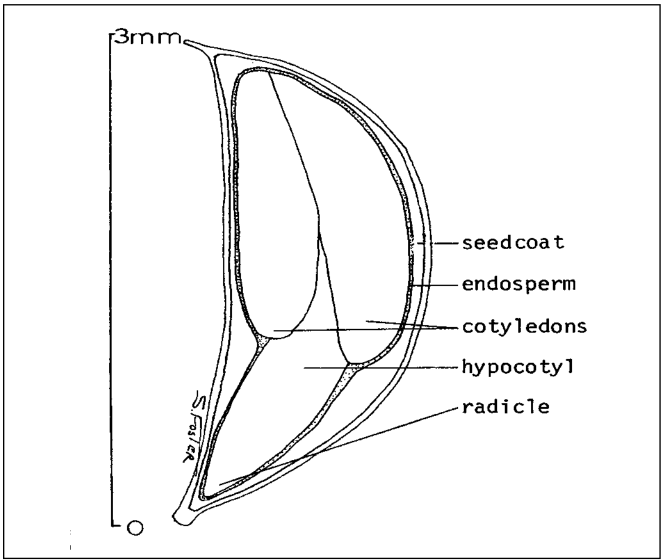


Figure 2—*Lophostemon confertus*, brushbox: longitudinal section through *a* seed.



Collection, extraction, and storage. In Hawaii, the capsules are picked by hand when they turn from green to greenish brown in color. They should be spread out on trays or tables to complete the drying process. Once the capsules are dry, simple agitation will separate the seeds from the capsules. There are almost 5 million seeds/kg (2.2 million/lb), but as few as 2 or 3% of these may be viable (Petteys 1974). The seeds are orthodox in storage behavior, as they have stored well in sealed polyethylene bags at low moisture contents and temperatures of –18 to –23 °C (Petteys 1974).

Germination. Brushbox is not dormant and no pregermination treatments are necessary for timely germination. Germination of full seeds for one group of samples averaged about 70% (Petteys 1974).

Nursery and field practice. Brushbox seeds are mixed with fine soil and the mixture is applied to beds with a fertilizer spreader. Germination usually begins in 10 to 14 days. Mulching and shading are not necessary. Seeds are usually sown from November to March and seedlings are outplanted the following winter as 1+0 stock. Bed densities of 215 to 320 seedlings/m^2 (20 to 30/ft^2) are recommended. Seedlings must be treated and planted with care to minimize the high mortality common to this species (Petteys 1974).

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Pinaceae—Pine family

Tsuga Carr.

hemlock

Jill R. Barbour, Robert H. Ruth, and Robert P. Karrfalt

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Growth habit, occurrence, and use. Trees of the hemlock genus—*Tsuga* spp.—are tall, straight, late successional climax evergreens with conical crowns and slender, horizontal to pendulous branches. Fourteen species have been reported; 4 of these are native to the United States and the others to the Himalayas, China, Taiwan, and Japan. The name *tsuga* is a Japanese word meaning "tree-mother" (Dirr 1998). Native American names for the North Country (that is, Canada), *hoe-nadia*, and for the lands of upper New York, *oh-neh-tah,* both mean "land of the hemlock" (Dirr 1998).

Of the 4 native species in the United States (table 1), both eastern and western hemlocks are used commercially for lumber and pulpwood. The bark of eastern hemlock has been a source of tannin for the leather industry. In central and southern Oregon and some other areas, mountain hemlock has become an important part of the softwood sawtimber volume.

Much of eastern hemlock has been severely affected by the hemlock woolly adelgid—*Adelges tsugae* Annand—in New England and the mid–Atlantic region (Dirr 1998). The hemlock woolly adelgid has also been noted on Carolina hemlock in the Tallulah Gorge in northeastern Georgia (Price 2002). Although the hemlock woolly adelgid occurs on mountain and western hemlocks from southern California to southeastern Alaska, these 2 species are resistant to the insect (McClure and others 2001).

Carolina hemlock overlaps the southern range of eastern hemlock, but it is a smaller tree with longer needles and cones. The wood serves the same uses as eastern hemlock, but the species is not abundant and of only minor commercial importance. Carolina hemlock is especially suitable for ornamental plantings.

Mountain hemlock is important mainly for watershed protection and the scenic beauty it adds to subalpine environments of Pacific Northwest mountain ranges. Its populations are disjunct due to the physical separation of its high-elevation sites. Due to the disjunct nature of its distribution, mountain hemlock was included in a world list of threatened species (Farjon and others 1993). It varies in size from a sprawling shrub at the timberline to a medium-sized forest tree.

Geographic races. Eastern, western, and mountain hemlocks have long north–south ranges and grow in a variety of habitats. Through natural selection, they apparently have developed numerous genetic types, each adapted to its local habitat.

Table 1—*Tsuga*, hemlock: nomenclature and occurrence

Scientific name	Common name(s)	Occurrence
T. canadensis **(L.) Carr.**	**eastern hemlock,** Canada hemlock, hemlock	Nova Scotia to S Ontario, S to N Georgia & Alabama
T. caroliniana **Engelm.**	**Carolina hemlock**	Mountains of Virginia to South Carolina to Georgia & Tennessee
T. heterophylla **(Raf.) Sarg.**	**western hemlock,** Pacific hemlock, hemlock	Pacific Coast from Alaska to Washington, Oregon, & California & in mtns of N Idaho & NW Montana
T. mertensiana **(Bong.) Carr.**	**mountain hemlock,** black hemlock	Pacific Coast regions from Cook Inlet, Alaska, to central California & to W Montana

Source: Ruth (1974)

A series of experiments with eastern hemlock (Baldwin 1930; Nienstaedt 1958; Olson and others 1959; Stearns and Olson 1958) showed that seedlings grown from southern seed sources tend to harden-off and go dormant later in the autumn and make more total growth (and the seeds requires less stratification) than those from northern sources. Southern seeds germinate best when temperatures approach 21 °C, whereas northern seeds do best near 13 °C. Seedlings from southern sources planted in Wisconsin grew late into the fall and were damaged more severely by frost than were their northern counterparts.

Similar results were obtained with western hemlock from 18 western provenances planted at various sites in Great Britain. Western hemlock seedlings from southern parts of this species' native range grew faster and set terminal buds later in the season than those from the North. However, when planted in northern Great Britain, they suffered severe damage from frost and cold winds. Frost damage was reduced if seedlings were planted under a high forest cover (Lines and Aldhous 1962, 1963; Lines and Mitchell 1969). Seed weight was found to decrease significantly from south to north, with collections from Alaska expected to have at least 110,000 more seeds/kg (50,000/lb) than western hemlock seeds from Oregon (Buszewicz and Holmes 1961). Kuser and Ching (1981) found significant differences among provenances in 100-seed weights, but there were only low correlations of seed weight with latitude, elevation, or distance from the Pacific Ocean. An increase in elevation on Vancouver Island, British Columbia, tended to increase germination rate and total germination (Edwards 1973).

Provenances of western hemlock with the fastest growing seedlings are from the southern part of the range; those with the slowest growing seedlings are from the northern part of the range as well as from the upper elevational extremes in the Rocky Mountains (Kuser and Ching 1981). In the case of western hemlock, the tree seed zones delineated by the Western Forest Tree Seed Council (WFTSC 1966b) may be used in Oregon and Washington. Those developed by the Organization for Economic Cooperation and Development (Piesch and Phelps 1970) may be used in British Columbia. A seed transfer zone map has been published for Oregon (Randall 1996).

Jeffrey hemlock—*Tsuga* × *jeffreyi* (Henry) Henry—has been reported as a cultivated hybrid of western and mountain hemlocks (Little 1979; Means 1990; Rehder 1949). Some French taxonomists proposed that mountain hemlock itself is an intergeneric hybrid of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock and they renamed it *Tsuga–Picea hookeriana* (Campo-Duplan and Gaussen 1948; Vabre-Durrieu 1954a&b). They considered a California form of mountain hemlock known as *Tsuga crassifolia* Flous to be a cross of mountain hemlock and Engelmann spruce (*Picea engelmannii* Parry ex Engelm). These hypotheses were rejected by American foresters, largely because of the absence of backcrosses and hybrid swarms in the field (Duffield 1950; Means 1990).

Many horticultural varieties of hemlock, including compact, weeping, spreading, and columnar forms, have been described (Dallimore and Jackson 1957; den Ouden and Boom 1965; Rehder 1940, 1949; Swartley 1945). They are widely planted as ornamentals throughout the temperate parts of the Northern Hemisphere.

Flowering and fruiting. Hemlocks are monoecious plants. Male and female strobili develop in clusters near the ends of lateral branches; each one consists of a central axis with spirally arranged microsporophylls. The male sporangia open transversely and the pollen is simple (Radford and others 1968). In mountain hemlock, pollen release is both protogynous and synchronous with female receptivity (Means 1990). The pollen is extremely sensitive to drying, which can prevent seed development in eastern hemlock (Godman and Lancaster 1990).

Ovulate strobili are erect, with nearly orbicular scales (each scale has 2 basal ovules), subtended by a membranous bract about the same length as the scale; they occur terminally on the lateral shoots of the previous year. In western hemlock, the total number of ovuliferous scales per cone is about 23 and about 70% of the scales are fertile (Colangeli and Owens 1989a). High temperatures in July the year before cone production favor flower initiation in mountain hemlock (Means 1990).

Hemlock is the only genus of the Pine family in which the mechanism of pollination involves nonmicropylar germination. Because of this difference, western hemlock seed cones are receptive for a much longer period than those of other conifers. Cones are receptive from shortly after bud burst until cone closure. The average number of days between bud burst and cone closure for western hemlock was 34 days in 1983 and 23 days in 1984 (Colangeli and Owens 1989a). Maximum pollination and seed efficiency (filled seed divided by the potential number of seeds per cone) is obtained when 50 to 75% of the cones have emerged beyond the cone scales (Bramlett and others 1977; Colangeli and Owens 1989a).

Hemlock pollen does not enter the cone micropyle but attaches to the waxy layer of the exposed portion of the bracts and ovuliferous scales. The bracts of western hemlock can trap more than 100 pollen grains, the average pollen grain count per bract from controlled pollinations being 34, with a range from 2 to 116 (Colangeli and Owens 1989a). The ovuliferous scales elongate over the bracts, trapping the pollen between the bracts and scales. About 4 to 7 days after pollen germination, the pollen tubes grow into the micropyles; usually 1 to 6 pollen tubes and sometimes up to 10 pollen tubes have been found in each micropyle (Colangeli and Owens 1989a). In western hemlock, pollen is not essential for seed cone enlargement and unpollinated ovules can continue seedcoat development, but the seed will not have an embryo or gametophytic tissue (Colangeli and Owens 1990a).

Cones mature in 1 season and are small, pendant, globose to ovoid or oblong, with scales longer than the bracts (figure 1). Carolina hemlock has the largest seeds of the native hemlocks, followed by mountain hemlock and eastern hemlock, with western hemlock having the smallest seeds (table 2; figure 2). Eastern hemlock has the smallest cones; they measure 1.5 to 2.5 cm by 1 to 1.5 cm. Eastern hemlock trees grown from eastern and southern sources have larger cones than do those grown from northern and western sources (Godman and Lancaster 1990). Western hemlock cones measure 1 to 3.0 cm by 1to 2.5 cm; Carolina hemlock cones measure 2.5 to 4 cm by 1.5 to 2.5 cm. Mountain hemlock have the largest cones, which measure 3 to 6 cm by 1.5 to 3 cm (FNAEC 1993; Harlow and Harrar 1968; Hough 1947; Sargent 1933).

Cone production of hemlock usually begins when trees are 20 to 30 years of age, a little later if trees are shaded. All 4 species of hemlock bear some cones almost every year and large crops are frequent (table 3). Cones often remain on the hemlocks well into the second year, being especially conspicuous on the tops of mountain hemlock. Wisconsin had good eastern hemlock cone crops on 61% of the 32 years recorded (Godman and Lancaster 1990). Eastern hemlock trees as old as 450 years have been seen bearing cones. Western hemlock bear cones every year with heavy crops every 3 to 4 years; in Alaska good crops occur every 5 to 8 years (Packee 1990). In Washington and Oregon, mountain hemlock trees 175 to 250 years old bear medium to heavy cone crops at 3-year intervals (Means 1990). Despite the frequency of cone crops, seed viability in hemlocks is generally low. Less than half the seeds in a cone are viable (Burns and Honkala 1990).

The period of dissemination of western hemlock seeds (table 4) can extend over a full year but the seeds are only viable during their first growing season (Packee 1990; Harris 1969). Most western hemlock seeds fall within 610 m from the tree, whereas eastern hemlock seeds fall within tree height due to their small wings (Godman and Lancaster 1990). Seeds remaining in cones are usually sterile in eastern hemlock.

Figure 1—*Tsuga*, hemlock: cones of *T. canadensis*, eastern hemlock (**upper left**); *T. mertensiana*, mountain hemlock (**lower left**); *T. carolina*, Carolina hemlock (**center**); and *T. heterophylla*, western hemlock (**right**).

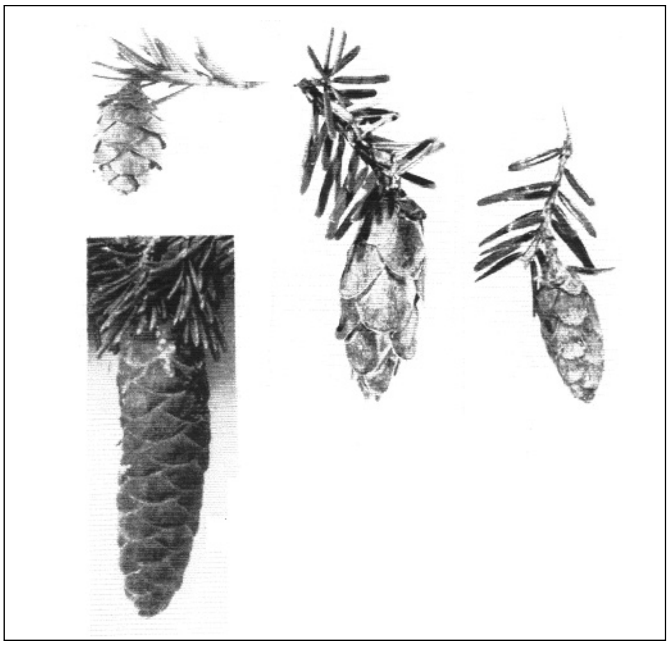


Table 2—*Tsuga*, hemlock: seed yield data

	Seeds (x1,000)/weight				
	Range		Average		
Species	/kg	/lb	/kg	/lb	Samples
T. canadensis	273–794	124–360	412	187	69
T. caroliniana	167–213	76–97	—	—	2+
T. heterophylla	417–1,120	189–508	573	260	106
T. mertensiana	132–459	60–208	251	114	6

Sources: Burns and Honkala (1990); Buszewicz and Holmes (1961), Hill (1969), Rafn (1915), Toumey and Korstian (1952), Toumey and Stevens (1928), Ruth (1974).

Table 3—*Tsuga*, hemlock: height, seed-bearing age, seedcrop frequency, and cone ripeness criteria

Species	Height at maturity (m)	Year first cultivated	Minimum seed-bearing age (yr)	Years between large seed-crops	Cone ripeness criteria: Pre-ripe color	Cone ripeness criteria: Ripe color
T. canadensis	18–30	1736	20–30	2–3	Yellow-green	Purple-brown
				15	Green	Tan to brown
T. caroliniana	12–21	1881	—	—	Purple	Light brown
T. heterophylla	18–75	1851	20–30	5–8	Green with purple tips	Brown with red-brown tips
T. mertensiana	7.5–45	1854	20–30	1–5	Yellow-green to brown	Brown

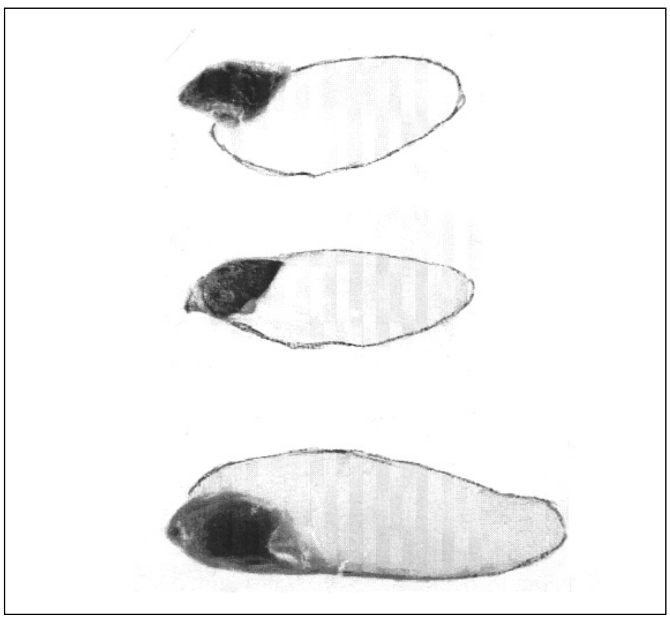
Sources: Burns and Honkala (1990), den Ouden and Boom (1965), Franklin (1968), Frothingham (1915), Harlow and Harrar (1968), Harris (1969), Hough (1947), Merrill and Hawley (1924), Olson and others (1959), Ruth (1974), Ruth and Berntsen (1955), Sudworth (1908).

Table 4—*Tsuga,* hemlock: phenology of flowering and fruiting

Species	Location	Flowering	Fruit ripening	Seed dispersal
T. canadensis	Southern range to northern range	Apr–early June	Sept–Oct	Sept–winter
T. caroliniana	North Carolina to South Carolina	Mar–Apr	Aug–Sept	—
T. heterophylla	Oregon to Washington	Apr–May	Sept–Oct	Oct–May
	S British Columbia	—	Sept 15	Oct–June
	SE Alaska	Late May-June	Sept–Oct	Oct
	W central Oregon	Mid to late Apr	—	Sept–May
	Idaho	May 27–June 5	Aug	Sept 17–winter
T. mertensiana	Oregon	June	Late Sept–Oct	—
	British Columbia, Alaska	June–mid-July	Late Sept-Nov	—
	Bitterroot Mtns, Idaho	Aug	—	—

Sources: Allen (1957), Burns and Honkala (1990); Ebell and Schmidt (1963), Frothingham (1915), Garman (1951), Gashwiler (1969), Godman (1953), Green (1939), Harris (1967), Harris (1969), Heusser (1954), Hough (1947), James (1959), Leiberg (1900), Radford and others (1964), Ruth (1974), Ruth and Berntsen (1955).

Figure 2—*Tsuga*, hemlock: seeds of *T. canadensis*, eastern hemlock (**top**); *T. heterophylla*, western hemlock (**center**); and *T. carolina*, Carolina hemlock (**bottom**).

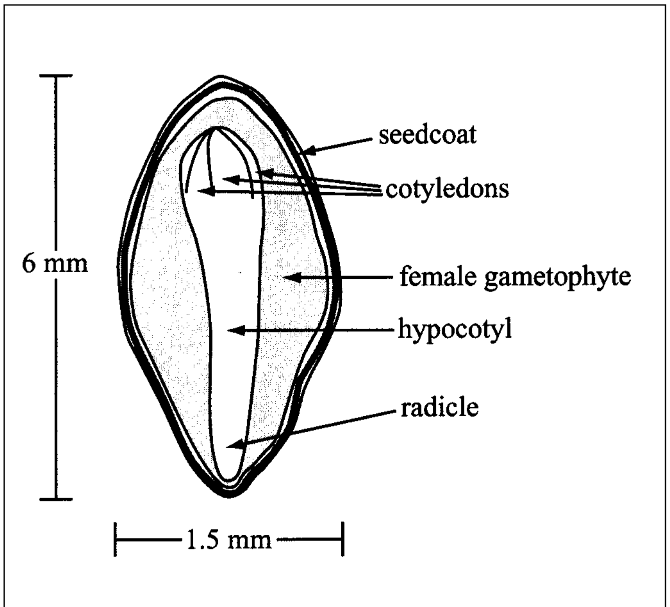


Western hemlock generally produces less than 40 seeds per cone; usually less than 20 of these are filled (Edwards 1976). At a clone bank in Victoria, British Columbia, the average number of seeds per cone was 34, and 22 seeds were filled when counted in 1983 and 1986 (Colangeli and Owens 1990b). The number of filled seeds counted on the exposed cut-face of a cone is a good predictor of total filled seeds per cone (Meagher 1996). The number of cones needed to estimate total filled seeds within ± 5 seeds ranged from 3 to 60 cones (Meagher 1996).

Prepollination ovule abortion produces small, flat seeds. Colangeli and Owens (1990b) found that it accounted for an average of 11 and 14% reduction in filled-seed yield in 1983 and 1986, respectively. Postpollination ovule abortion occurred in about 4% of the ovules, corresponding to less than 1 seed per cone (Colangeli and Owens 1990b). Insufficient pollination—which is usually the reason for low seed set—resulted in 25% empty seeds in 1983 and 66% empty seeds in 1986 (Colangeli and Owens 1990b).

Embryos have 3 to 6 cotyledons (figure 3) (Sargent 1933). Kuser and Ching (1981) found provenance variation

Figure 3—*Tsuga mertensiana*, mountain hemlock: longitudinal section through a seed.



in cotyledon number in western hemlock. Seedlots from the Rocky Mountains produced higher frequencies (15%) of 4-cotyledon seedlings than those from the Cascade Mountains or coastal zones (11%). The embryo extends the full length of the seed. Olson and others (1959) reported that embryos from eastern hemlock are about 3 mm long and 0.5 to 0.7 mm in diameter.

Collection of fruits. Hemlock cones are small and, therefore, more difficult to harvest than the larger cones of many conifers. They are most easily collected from tops of trees felled during harvest cuttings, but it is important that seeds from such collections are checked for maturity. Usually cone collection is delayed until shortly before seed dispersal to ensure full maturity of the seeds. Cones also can be harvested by the use of ladders, pole pruners, and various kinds of climbing equipment.

Based on a study of western hemlock in southern British Columbia, Allen (1958) recommended September 15th as a suitable date to begin cone collection even though cones are still green and hard. Seeds collected earlier (August 30th) had lower total germination. The germination rate of seeds collected September 15th was improved by storage and stratification. Seeds of western hemlock cones that are stored for 3 to 6 months before seed extraction had higher percentages of germinating seeds (91%) than did seeds from cones stored for 1 month before extraction (75%) (Leadem 1980). Also working with western hemlock, Harris (1969) found a few seeds viable when extracted as much as 70 days before seed dispersal. When cones were left on the tree, the percentage viability increased gradually until almost dispersal time.

Extraction and storage of seeds. Handling procedures for hemlock cones and seeds follow those of other conifers. Usually cones are stored—often for several weeks and sometimes months—in permeable sacks in open-sided cone drying sheds while awaiting processing. This covered storage serves as a preliminary curing process. Green cones tend to mold during storage, especially if stored without surface drying. Adequate air circulation is needed around each sack to minimize heating and mold buildup. Under proper conditions, western hemlock seeds may remain in the cones up to 6 months without detrimental effects upon seed quality. Leadem (1980) found that seeds from cones refrigerated at 2 °C had no better quality than seeds from cones stored outdoors.

An additional, or sometimes alternate, procedure is to place cones in a heated room for up to 36 hours before actually placing them in a drying kiln. This avoids exposing seeds that are nearly saturated with water to high kiln temperatures, a procedure that damages some conifer seeds. It also reduces kiln time and cost.

There are few problems in extracting seeds from hemlock cones. According to Baldwin (1930), mature hemlock cones need little artificial heat to open. Kiln-drying temperatures range from 31 to 43 °C, with drying time about 48 hours (Deffenbacher 1969; Isaacson 1969; Ruth 1974; Ward 1969). In the West, few hemlock cones are processed, and kiln schedules generally follow those for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and pine (*Pinus* spp.).

Eastern hemlock cones that are picked green, and thus are difficult to open, usually can be opened by exposure to repeated cycles of moistening followed by drying at 38 °C. Eastern hemlock cones collected just as they turn tan will open readily upon drying (Olson and others 1959). Mold-infested cones often open poorly, making seed extraction difficult. Seeds are extracted by tumbling or shaking the cones during or immediately after kiln-drying. On the tree, western hemlock cones open and close readily in response to changing moisture conditions and require many flexings of the cone scales before all seeds are dislodged; with kiln-drying and tumbling or shaking, a single opening of the cone scales appears sufficient for good seed extraction (Harris 1969).

Seeds are nearly surrounded by their wings (figure 2). Unlike the seeds of fir, Douglas-fir, and some pines, hemlock seeds have an entire wing that can be detached without serious damage to the seeds themselves (AOSA 2001).

Seeds are de-winged, and wing parts and foreign matter removed in a fanning mill or gravity separator. Minimum standards of 90% purity and 60% viability have been established for seedlots of western hemlock (WFTSC 1966a). The low viability often reported for eastern hemlock may be due to the difficulty of separating out low-quality seeds (Olson and others 1959). Care should be taken during processing to minimize the seed mortality that results from bruising or cracking the seedcoat.

For eastern hemlock, 0.35 hl (1 bu) of cones weigh about 15.5 kg (34 lb) or 1 liter (1 qt) of cones weights 0.44 kg (1 lb) (Eliason 1942) and yields 0.6 to 0.7 kg (1.4 to 1.5 lb) of seeds with a moisture content of 7.1% (Hill 1969; Toumey and Korstian 1952). Eastern hemlock seed yield per 100 kg (220 lb) of cones is 3.1 kg to 6.2 kg (6.8 to 13.6 lb) of seeds (Barton 1961; Ruth 1974). For western hemlock, there were 20,000 cones in 0.35 hl (1 bu) (Kummel and others 1944) and 0.45 kg (1 lb) of seeds was extracted from 0.35 hl (1 bu) of cones (Toumey and Korstian 1952).

Annual seeding and planting programs are dependent on successful seed storage (table 5). Western hemlock seeds keep best below freezing, and general practice is to store them at –18 °C. Barton (1954a) showed that viability was maintained better at this temperature than at –11 or –4 °C, with distinct differences showing up after only 2 years of storage. Viability can be maintained for at least 5 years, and this generally bridges the gap between large seedcrops.

Eastern hemlock seeds are stored both above and below freezing. They have been kept for 2 to 4 years in jars or plastic bags in a refrigerator maintained a few degrees above freezing, but retention of viability varied between seedlots (Olson and others 1959).

Mountain hemlock seeds are also stored at –18 °C. Mountain hemlock seedlots vary in their ability to withstand short-term stress, indicating that the genetic makeup of the seedlot may affect long-term seed storage. Accelerated aging (37.5 °C) treatments, varying from 0 to 21 days at 3-day intervals on mountain hemlock seeds, resulted in a complete loss of viability for stratified seeds at 12 days and for unstratified seeds at 18 days (El-Kassaby and Edwards 1998). The average viability for stratified seedlots decreased from 88% before aging to 3.6% after 9 days of aging. The average viability for unstratified seedlots decreased from 91% to 2% over the same time period (El-Kassaby and Edwards 1998).

Table 5—*Tsuga,* hemlock: seed storage conditions

Species	Seed moisture (%)	Temp (°C)	Viable period (yrs)
T. canadensis	—	5	4
	6–8	1–3	—
	—	–3	—
T. heterophylla	7–9	–18	5–7
	6–8	0	—
	8	–18	5+
	8	–18	3+
	—	21	2–3

Sources: Allen (1957), Barton (1954b, 1961), Jones (1962), Ruth (1974).

Moisture content of hemlock seeds in storage should be maintained between 6 and 9%. In longevity tests of seedlots stored at 5 °C with 6 to 10% moisture contents, a seedlot of western hemlock had 13% germination after 15 to 16 years, and another of mountain hemlock had 2% after 11 to 20 years (Schubert 1954). A study with western hemlock (Lavender 1956) demonstrated that temperatures and humidity levels generally experienced between removal of seeds from storage and seeding operations or testing procedures do not appreciably reduce viability. There was good viability retention of seeds removed from storage and stored at 20 °C and 30% relative humidity for as much as 11 weeks.

Pregermination treatments. Dormancy is variable in hemlock, with some seedlots requiring pregermination treatment and others germinating satisfactorily without treatment (Baldwin 1934; Bientjes 1954; Olson and others 1959). Because cold stratification (1 to 4 °C) of mature seeds shortens incubation time and may substantially increase germination, cold stratification is recommended prior to testing (except for seeds known to be nondormant) (table 6).

Stratification clearly accelerates and improves total germination of eastern hemlock (Baldwin 1930, 1934; Stearns and Olson 1958). For eastern hemlock seeds that have not been stratified, germination is improved by exposing seeds to 8- to 12-hour photoperiods at a temperature of about 21 °C alternating with dark periods at about 13 °C (Olson and others 1959). A long stratification period (70 days) increased germination percentages for Coffman (1975), who germinated seeds at 18 °C in darkness or with a $^1/_2$ hour of red light daily (615 nm, 0.056 g-cal/cm^2/min). Viable stratified, irradiated seeds showed 58% germination; viable stratified, non-irradiated seeds showed only 37%. Coffman also found that gibberillic acid (GA), kinetin, or a mixture of the two, inhibited the effect of prechilling, even in the presence of red light. There was nearly a complete lack of germination of unstratified eastern hemlock seedlots kept under red light (Coffman 1975).

Table 6—*Tsuga*, hemlock: stratification treatments

Species	Medium	Temp (°C)	Time (days)
T. canadensis	Moist sand or peat	1–5	30–120
T. caroliniana	Peat moss	3–5	30–90
T. heterophylla	Moist sand	1–5	21–90
	Plastic bag*	1–2	21–56
T. mertensiana	Moist sand	5	90

Sources: Allen (1958), Babb (1959), Deffenbacher (1969), Devitt and Long (1969), Eide (1969), Olson and others (1959), Ruth (1974), Swingle (1939), Walters and others (1960), Ward (1969), Weyerhaeuser (1969).
* Seeds were presoaked in tap water for 24 to 36 hours.

Germination of eastern hemlock seeds declines depending on the frequency and degree of drying following the imbibition phase and on the intensity of light. Eastern hemlock seeds incubated in open petri dishes at a low light level (645 lux) showed various germination values, from 50.2% with decomposed birch medium to 0% with filter paper. Seeds incubated in open petri dishes with decomposed birch medium that were exposed to a moderate light level (4,682 lux) exhibited delayed initial germination and significantly reduced total germination to half that at low light conditions (Coffman 1978). The intensity of light had no effect on seeds in covered petri dishes where a high moisture content was maintained.

Seeds of western hemlock stratified for 3 weeks at 1 °C germinated faster than untreated seeds; longer stratification periods caused additional but smaller increases in the rate of germination (Bientjes 1954; Ching 1958). Stratification of western hemlock seeds apparently has its main effect on speed of germination; it has only a minor effect on total germination percentage. Seedlots stratified for 1 week reached R_{50} (the number of days to reach 50% germination) 2.5 days sooner than did unstratified seedlots. Seedlots stratified for 4 weeks reached R_{50} 4.5 days sooner, and seedlots stratified for 16 weeks reached R_{50} 10.5 days sooner than did unstratified seedlots (Edwards 1973). Unstratified seedlots of western hemlock required nearly 2.5 weeks (18 days) to produce the same number of germinants as did seedlots stratified for 3 months in 10 days (Edwards 1973). Western hemlock seeds stratified for 1 week in plastic bags germinated about 1 day sooner than seeds stratified on filter paper (Edwards 1973). Presoaking the seeds for 48 hours was as effective in reducing the germination rate as was 1 week of stratification on filter paper (Edwards 1973). Immature western hemlock seeds tend to have lower total germination as a result of stratification (Allen 1958).

Experiments in Great Britain showed slightly increased rates of germination following stratification when western hemlock seeds were exposed to light but none when they were germinated in darkness (Buszewicz and Holmes 1961). Stratified western hemlock seeds tended to reduce the sensitivity to photoperiod (Edwards and Olsen 1973). Germination rate increased under a 4-hour photoperiod (300 to 350 foot candles or 3,228 lux); whereas 16 hours or more of photoperiod depressed germination rate below those in complete darkness at a constant 20 °C temperature (Edwards and Olsen 1973). Eight hours of light did not have a difference in germination from the no light treatment (Edwards and Olsen 1973).

Light significantly reduces germination rate for mountain hemlock seeds regardless of stratification. Unstratified and stratified seeds germinated in 8 hours of light (100 lux at filter paper surface) a week later than seeds grown in darkness (Edwards and El-Kassaby 1996). The R_{50} values for seeds incubated in light was almost double (6 days more) that of seeds incubated in darkness (Edwards and El-Kassaby 1996). Stratification increased the speed of germination slightly, but it did not alleviate the light effect nor did it effect total germination (Edwards and El-Kassaby 1996). Mountain hemlock seeds germinated 91% in the dark and 90% with light: mountain hemlock seeds can germinate as well or better without light (Edwards and El-Kassaby 1996).

Germination may begin while seeds are still in stratification if kept too long, with subsequent problems of drying out and mechanical damage during sowing. Careful regulation of seed moisture content and temperature can prevent germination from beginning in stratification. Seeds need to be kept at full imbibition but surplus water should be totally or mostly removed. Radicals will only elongate with surplus water present. Keeping temperatures closer to freezing and constant is also a good precaution. Temperature in the 1 to 2 °C range will retard germination more effectively than allowing temperatures to rise to near 5 °C. Personnel should limit entry into the stratification cooler to minimize temperature fluctuations.

Germination tests. The Association of Official Seed Analysts (AOSA 2001) have prescribed standard germination test conditions for eastern and western hemlocks (table 7). It is recommended that eastern hemlock seeds be prechilled for 28 days at 3 to 5 °C followed by 28 days in a germinator at 15 °C. The rules call for placing western hemlock seeds directly in germinators at 20 °C for 28 days. Stratification is not required as part of the standard germination test procedure for western hemlock seeds but a paired germination test with 21 days of stratification can be performed and it is common practice to stratify seeds prior to nursery sowing. Seeds of both species should be exposed to light no more than 8 hours daily during this period. A tetrazolium staining technique for estimating seed viability may be used on western hemlock, but results may tend to underestimate seed quality (Buszewicz and Holmes 1957).

The International Seed Testing Association (ISTA 1999) rules used for exporting seeds are similar to domestic rules except that the germination test period for western hemlock is extended to 35 days. Standard procedures have not been developed for Carolina and mountain hemlock, so test conditions follow those for the associated eastern or western hemlocks.

Mountain hemlock seed germination is very sensitive to the total accumulation of heat even though it has been known to germinate on snow but much more slowly (Franklin and Krueger 1968). Stratification as long as 120 days does not compensate for sub-optimal temperatures. For mountain hemlock seed testing germination, stratification for 90 days at 4.5 °C is recommended with germination temperature set at a constant 20 °C (480° daily heat sum) (table 6).

In a laboratory study, as the heat sums rose from 280 to 440% daily heat sums the germination rate increased but final germination was not affected by temperature (El-Kassaby and Edwards 2001). Heat sum is the addition of temperatures above 0 °C for 24 hours. The threshold heat sum for mountain hemlock seed germination lies close to 400% daily heat sum which does not occur at high elevations until August in British Columbia, Canada (El-Kassaby and Edwards 2001). Stratification treatments did not have a significant effect on rate or final germination (El-Kassaby and Edwards 2001).

Correlations between latitude and total germination (r= 0.482) and between mountain hemlock seed weight and latitude (r = – 0.482) were found to be significant (*p* less than

Table 7—*Tsuga*, hemlock: stratification period, germination test conditions, and results

			Germination test condions†						
	Cold strati-fication*	Daily light period	Temp (°C)			Germination rate		Germin-ation	
Species	(days)	(hrs)	Day	Night	Days	(%)	(days)	(%)	Samples
T. canadensis	60–120	—	30	20	60	10–55	15–30	38	15
	0–30	—	22	22	—	6–62	28	10–66	9–12
	21–30	8	16	16	28	—	—	—	—
	20	8	15	15	28	—	—	60	3
	40	8	15	15	28	—	—	45	3
	90	8	15	15	28	—	—	61	9
T. caroliniana	0	8	30	20	28	—	—	40–80	9
	21–30	8	30	20	28	—	—	51–57	3
	0–120	16	22	22	34	—	—	82–91	5
T. heterophylla	0	8	20	20	28–35	49	21	53	146
	0–90	—	16	11	30	38	20–30	56	25
	0	8	15	15	35	—	—	86	44
	28	8	15	15	35	—	—	86	43
T. mertensiana	0–90	—	30	20	25–30	62–75	16–20	47	4
	—	Dark	20	20	28	—	—	91	19
	—	8	20	20	28	—	—	90	19
	90	—	30	20	60	61	16	62	1
	0	8	20	20	28	—	—	81	4
	28	8	20	20	28	—	—	97	3
	90	8	20	20	28	—	—	72	5

Sources: AOSA (2001), Buszewicz and Holmes (1961), Edwards and El-Kassaby 1996, Hill (1969), ISTA (1999), Ruth (1974), USDA FS (2002)
* Temperatures were –16 to –15 °C.
† Moisture-holding media were either blotters, Kimpak®, sand, or peat.

or equal to 0.05) (Edwards and El-Kassaby 1996). As seed source was moved further north in latitude, the seed weight decreases because the seeds are smaller. Germination parameters are under strong genetic control with broad sense heritabilities, h_2, ranging from 0.30 to 0.85 for stratified seeds and 0.45 to 0.84 for unstratified seeds (El-Kassaby and Edwards 1998).

Final germination percentage of western hemlock seeds is affected by germination temperature. Greater total germination occurred at a constant temperature of 20 °C than under lower, higher, or alternating temperatures (Bientjes 1954; Buszewicz and Holmes 1961; Ching 1958). When alternating temperatures are used, keeping seeds in the dark improves germination (Buszewicz and Holmes 1961).

Western hemlock seeds from northern populations tended to germinate early, by about 4 days/degree of latitude, at 7 °C after 10 days of chilling (Campbell and Ritland 1982). Western hemlock seeds from high-elevation populations in the coast range germinated more rapidly than seeds from low or middle elevation population. For populations in the Cascades, seeds from both high- and low-elevation sources germinated more rapidly than seeds from middle elevations (Campbell and Ritland 1982). Lengthening stratification tended to decrease differences among provenances.

Observations of eastern hemlock (Olson and others 1959) illustrate ontogeny of seed germination, which is epigeal (figure 4). The first indicator of a viable seed is splitting of the seedcoat for half to two-thirds of its length, followed by the appearance of the pointed, bright-red root tip. The root grows at the rate of 2 to 3 mm/day, curving abruptly after emergence. After a few days, the hypocotyl also begins to grow, reaching 2 to 3 cm in length in 1 to 3 weeks. Normally, there is a pause in development after the cotyledons open, which may arbitrarily be considered the end of germination.

Figure 4—*Tsuga canadensis*, eastern hemlock: seedling development at 2, 4, and 7 days after germination.

Nursery practice. Hemlock seedlings are difficult to grow in the nursery. They are easily damaged in the hot sun, and their small size the first year makes them particularly susceptible to frost heaving. Because of these difficulties, natural regeneration has in the past been favored over planting seedlings. Natural regeneration of western hemlock usually has been adequate, and a common procedure for mixed stands is to plant or seed associated species and expect hemlock to come in on its own, which it usually does. With increasing intensity of management, demand for western hemlock seedlings has increased, and production procedures were developed (Deffenbacher 1969; Devitt and Long 1969; Eide 1969; Isaacson 1969; Ward 1969; Weyerhaeuser 1969).

At some nurseries (Eide 1969; Weyerhaeuser 1969), western hemlock seeds are soaked for 24 to 36 hours prior to stratification. The speed of germination was increased by soaking seeds in tap-water for 33 hours at room temperature (Bientjes 1954). Prolonged soaking for 96 to 120 hours, however, reduced the germination rate (Ching 1958).

Most nursery managers stratify western hemlock seeds and sow them in the spring. Seeds are moistened, excess water drained off, then the seeds are stratified at 1 to 2 °C from 21 to 42 days in a polyethylene bag. No stratification medium is used. Seed moisture content for optimum germination should be about 60% (Devitt 1969). Soil moisture content should be high but with drainage adequate to keep the ground water level below the rooting zone. Seedbeds may need screening to protect seeds from birds and rodents.

At one nursery (Eide 1969), seeds were sown on the surface and covered with burlap and sprinkled as needed to maintain moisture. After germination and penetration of the radicle into the soil, the burlap is removed and seedlings are mulched with peat moss. Additional peat moss is added during the growing season. Seedlings go into the winter with 13 to 19 mm ($^1/_2$ to $^3/_4$ in) of mulch to minimize frost heaving. About 50% shade is provided the first season.

For nursery production of eastern hemlock seedlings, spring-sowing of stratified seed is preferred over fall-sowing (Hill 1969; Olson and others 1959). Good eastern hemlock seeds planted under favorable conditions usually survive superficial contamination with mold, and use of fungicides is not recommended unless serious contamination is present. Nursery seedlings are very subject to damping-off by *Rhizoctonia* spp. during the first few months after germination and this can be aggravated by over-fertilization. It can be prevented (and weed seeds killed) with fumigation. Damping-off after germination can be controlled with fungicide (Olson and others 1959). One nursery growing western hemlock treats seedbeds when necessary with captan or thiram and has not had a serious problem with damping-off diseases. They also have treated hemlock seedlings with animal repellant to protect them from damage after outplanting (Eide 1969).

In nursery experiments in Great Britain, partial soil sterilization with formalin drench or chloropicrin injection improved growth of western hemlock. Moderate to large height increases were obtained with either treatment. Both sterilants used together often gave even better growth response, although treatment effects were not additive (Benzian 1965).

Only a few reports are available on nutrient requirements of hemlock. Western hemlock in British Columbia requires a well-drained acid soil with pH about 4 to 5 and an organic matter content of 5 to 6% (Devitt 1969). In Washington, it grows well at pH 5.3 to 5.4 with at least 15% soil organic matter (Eide 1969). In Great Britain, western hemlock made maximum growth on acid soil at about pH 4.5 and responded favorably to fertilization with nitrogen, phosphorus, and potassium. It showed a definite tip burn when suffering a copper deficiency, but seedlings recovered when sprayed with Bordeaux mixture. Water deficits during a dry summer apparently prevent response to nitrogen fertilization (Benzian 1965), but on the other hand, late summer watering can delay hardening-off and may increase the risk of frost damage (Olson and others 1959).

Seedlings are small at the end of the first growing season in the nursery and usually are held over and lifted after the second or third season. Seedlings frequently are transplanted for 1 year and then outplanted as 2+1 or 3+1 planting stock (Devitt and Long 1969; Olson and others 1959; Ward 1969). To overcome the difficulties of germination and frost heaving in the bareroot bed, plug+1 or plug+2 seedlings are used more commonly now than directly sowing seeds in the nurserybed (Romeriz 1997). In this system, a miniplug seedling is started in the greenhouse and then transplanted to the bareroot nurserybed.

Desired densities range from 323 to 538 seedlings/m^2 (30 to 50/ft^2) and tree percentages run from 15 to 50 (Deffenbacher 1969; Devitt and Long 1969; Eide 1969; Isaacson 1969; Ward 1969; Weyerhaeuser 1969). Experience in Great Britain indicates that a large proportion of losses in the nursery occur before seedling emergence. A high variability in tree percentage requires large safety factors in nursery sowings, resulting in an occasional surplus of seedlings (Buszewicz and Holmes 1961). The use of western hemlock plug transplants (Klappart 1988) reduces the number of seeds used and produces a larger, higher quality seedling in less time (Smith 1997). The production of container seedlings for outplanting is also widely practiced for western hemlock (Smith 1997).

Most hemlocks are now grown in containers in greenhouses under intensive culture instead of in bareroot nurseries. Styrofoam® blocks are the most common containers used and the sizes vary from 60, 77, to 112 trees/block with 77 trees/block the most commonly used. There are two outplanting regimes that dictate the propagation procedure in the greenhouse. The spring-planting regime requires that seeds be sown around February 1st, with the seedlings outplanted in the spring of the next year. Seeds are sown around January 15th for the summer-planting regime, with the seedlings being outplanted in the summer of the same year (Girard 2002).

Seeds are stratified for 21 days before sowing to achieve rapid, uniform germination and are germinated at 20 to 25 °C with light. It is the usual practice to sow with equipment more than 1 seed per cavity when germination falls below 90%. Once the seeds are fully germinated the photoperiod is increased to 20 hours/day and maintained until late April to keep the terminal bud from setting prematurely. The container medium is usually peat moss that may be amended with perlite or fir sawdust. Containers are lightly filled with medium to allow hemlock's large root system to grow. Controlled-release fertilizer is added to the medium at 4 kg/m^3 of medium in addition to lime to raise the pH and trace elements. The seeds are lightly covered with a sandy grit. A complete soluble fertilizer is added to the irrigation water every time the seedlings are watered. Frequency of irrigation is determined by weighing the containers after watering and then re-irrigating once the container weight drops below the target level (Girard 2002).

The seedlings are induced to set a terminal bud in the greenhouse by photoperiod reduction achieved through retractable darkout systems. Western hemlock seeds from southern sources require about a 4-week darkout period of 10 hours/day of light and 14 hours/day darkness. Seeds from northern sources only require about 2 weeks of darkness in the July following sowing to set buds. The short-day induction period is not begun until the trees have reached a minimum height of 15 cm (77 cavities/block). Seedlings will continue height growth during the short-day treatment so it is important to initiate bud induction early enough to maintain a good shoot to root ratio. Following the darkout period, seedlings are subjected to moderate moisture stress to maintain budset. Nurseries favor greenhouse systems that have roofs that open to subject the planting stock to full light conditions following budset. In nurseries lacking those systems, containers are usually moved outside growing compounds (Girard 2002).

For 77 cavities/block stocktypes, the target seedling height for outplanting is 30 cm (12 in), with no more than a maximum of 40 cm (16 in) height. The minimum caliper for outplanting is 3 mm and the target is 3.5 mm. It takes about 25 weeks from sowing to grow a target seedling. For spring-planted crops, ambient greenhouse temperatures are reduced to about 2 °C in the late fall to further develop dormancy. A frost hardiness test is performed to determine dormancy before the seedlings are lifted for cold storage. A sample of seedlings are frozen to –15 °C and injury is determined through variable chlorophyll inflorescence (Girard 2002).

For extraction of seedlings from the growing containers, most nurseries use automatic pin extractor machines. The containers are laid on their sides and metal pins push the plugs out of the containers and the seedlings are then graded for quality. For summer outplanting (late August and early September), seedlings are not stored before planting. The seedlings are lifted while still growing, shipped, and planted within 24 hours (Girard 2002).

Spring-outplanted seedlings are lifted from containers in December and stored for up to 3 months in cold storage at –2 to –5 °C. Seedlings are placed in an upright position within a waxed cardboard box. Boxes filled with seedlings to be stored frozen have a brown paper liner with an inner plastic membrane to retain moisture. Frozen seedlings are allowed to thaw 3 to 5 days in a thawing shed before they are shipped to the field for planting (Girard 2002).

Eastern hemlock is sometimes propagated vegetatively. Dormant cuttings taken in January to mid-February should be placed in beds with bottom heat, but results can be variable (Dirr and Heuser 1987).

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