Fabaceae—Pea family

Pithecellobium dulce (Roxb.) Benth.

guamúchil

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Nomenclature. *Pithecellobium* is a genus of about 110 species, mostly native to Asia and tropical America. The taxonomy of this genus has been changed in recent years, and the names of some species are still in debate. *Pithecellobium saman* (Jacq.) Benth., which was included in the 1974 edition of this work (Walters and others 1974), became *Albizia saman* (Jacq.) F. Muell., then *Samanea saman* (Jacq.) Merr. In the current book, it is included in *Albizia*. Texas ebony (*P. flexicaule* (Benth.) Coult.) is now *Ebenopsis ebano* (Berl.) Barneby & Grimes and appears under that name in this book.

Growth habit, occurrence, and use. *Guamúchil*, also known as Madras thorn and monkeypod, is valued primarily for its fuelwood, fodder, and ornamental properties (Parrotta 1991). It is found on the Pacific slopes of Mexico and southern California, south to Colombia and Venezuela. Guamúchil has been planted in Florida, Puerto Rico, and Hawaii (Little and Wadsworth 1964) and has been introduced to India and Pakistan as a hedge plant (Khatra and others 1994). The species has become naturalized where planted and is now considered a pest in Florida (Morton 1976). It is a medium-sized tree that reaches heights of 22 m.

Flowering and fruiting. Guamúchil's white flowers are umbels, about 3 cm in length, that are borne in paniculate clusters on branch ends (figure 1). The species flowers primarily from December to May but is known to fruit throughout the year in Puerto Rico (Parrotta 1991). Fruits are linear, curved legumes (pods) that range in length from 10 to 13 cm (figure 1). They turn from green to brown or black when they ripen in February to August. The legumes may contain 5 to 12 seeds each, and they are dehiscent (Parrotta 1991). The seeds are reddish brown to black, elliptical, beanlike, and about 1 cm in length. As the legumes split open, the seeds often hang down partially enclosed in a pulpy aril that may be 2 cm long (figure 2). Seeds vary widely in size, ranging from 6,000 to 26,000/kg (2,720 to 11,800/lb) (Little and Skolmen 1989; Parrotta 1991).

Collection, extraction, and storage. Legumes may be picked from the trees or from the ground, and air-dried in the sun. Seeds can be removed by hand-flailing or by use of a macerator, and pod fragments can be removed with screens. There are no long-term seed storage data for guamúchil, but these are typical hardseeded legumes with orthodox storage behavior. The seeds should be easy to store at low moisture contents (<10%) and low temperatures (any refrigeration) for a number of years.

Germination. Official seed testing organizations do not include guamúchil in their prescriptions for testing, but tests with a single seedlot in Costa Rica found that germina-

Figure 1—*Pithecellobium dulce*, guamúchil: flowering twig, leafy twig, legumes, and seeds (from Little and Wadsworth 1964).

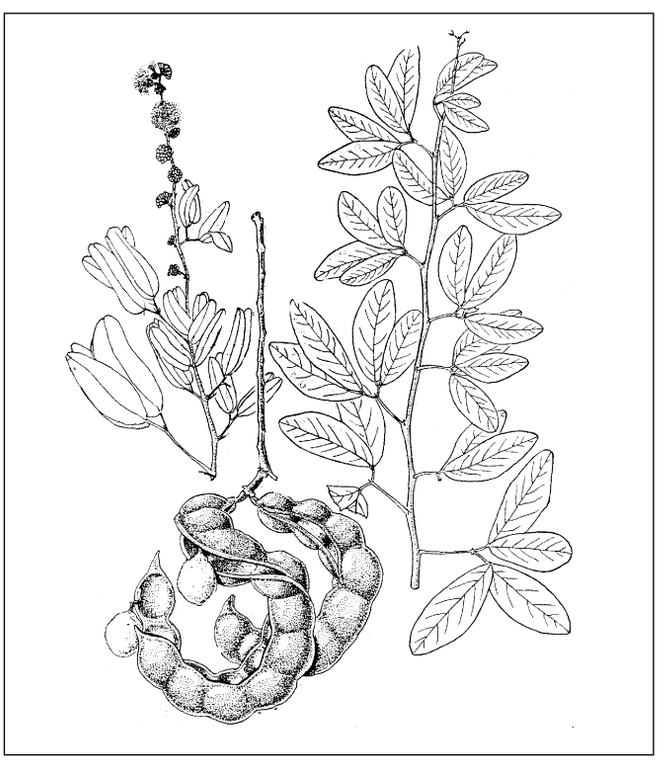
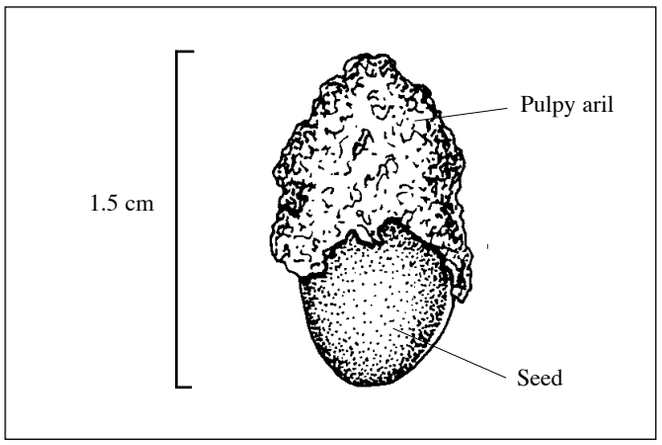


Figure 2—*Pithecellobium dulce*, guamúchil: seed partially enclosed in the pulpy aril (from Gunn 1984).



tion averaged 93% over a wide range of conditions (Castro 2000). Temperatures of 24, 27, 30, and 32 °C were equally good, and light from 0 to 24 hours made no difference either. Scarification with sulfuric acid or by clipping the seedcoats gave germination above 90%, but hot water treatments and long soaks at room temperature were not as successful. Good germination of this species without pretreatment has also been reported (Parrotta 1991).

Nursery practice. Guamúchil seeds germinate 1 to 2 days after sowing without treatment in Puerto Rico. Seedlings reach a good outplanting height of 40 cm about 3 months after sowing. This species can also be grown from cuttings (Parrotta 1991).

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Platanaceae—Planetree family

Platanus L.

sycamore

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Growth habit, occurrence, and uses. Sycamores—genus *Platanus*—are deciduous trees that range from 24 to 43 m in height at maturity. Two native and 1 introduced species are included in this manual (table 1). American sycamore is a large and valuable timber species in the eastern United States and has been widely planted in the Southeast for fiber production, wetlands restoration, and mine spoil reclamation (Haynes and others 1988; Wells and Schmidtling 1990). California sycamore is valued for watershed protection and wildlife food, whereas oriental planetree is primarily planted for ornamental purposes. London plane—*P.* × *aceriolia* (Ait.) Willd.—a hybrid between sycamore and oriental planetree, is also widely planted as an ornamental in the United States because of its tolerance of air pollution and alkali (Little 1961; Dirr and Heuser 1987). No geographic races of these species are recognized, but there is sufficient variation within American sycamore for growth (Ferguson and others 1977) and disease resistance (Cooper and others 1977) to justify tree improvement programs.

Flowering and fruiting. The minute monoecious flowers of sycamores appear in the spring (table 2). The dark red staminate flower clusters are borne on branchlets of the previous year's growth, and the light green pistillate flowers are found on older branchlets (Vines 1960; Wells and Schmidtling 1990). Sycamore fruiting heads are usually solitary, but California sycamore may have 2 to 7 heads grouped on a single stem (Bonner 1974) (figure 1).

Fruit heads are greenish brown to brown at maturity in the autumn (table 2). Those of sycamore are 25 to 40 mm in diameter, and those of the other species are closer to 25 mm. The true fruits are elongated, chestnut-brown, single-seeded achenes with a hairy tuft at the base (figure 2). They are closely packed, with their bases anchored in a hard central

Table 1—*Platanus,* sycamore: nomenclature and occurrence

Scientific name & synonym(s)	Common name(s)	Occurrence
***P. occidentalis* L.** *P. occidentalis* var. Sarg. *glabrata* (Fern.)	**American sycamore,** American planetree, buttonwood, planetree, buttonball-tree	Maine to Iowa, S to central Texas & NW Florida; also in NW Mexico; planted in South Dakota, Colorado, Nebraska, & Kansas
***P. orientalis* L.**	**oriental planetree**	SE Europe, W Asia to India; planted in US as an ornamental
***P. racemosa* Nutt.**	**California sycamore,** California planetree, western sycamore, *aliso*	Central to S California & into NW Mexico; below 1,200 m elevation

Sources: Little (1961, 1979).

Table 2—*Platanus,* sycamore: phenology of flowering and fruiting

Species	Location	Flowering	Fruit ripening	Seed dispersal
P. occidentalis	E US	Mar–May	Sept–Nov	Jan–Apr
P. orientalis	NE US	May	Sept–Oct	—
P. racemosa	—	—	June–Aug	June–Dec

Sources: Bonner (1974), Wells and Schmidtling (1990).

core. The elongated embryo is surrounded by a thin endosperm (figure 3). Sycamore usually bears good seed-crops every 1 to 2 years and light crops in the intervening years. Open-grown trees of this species as young as 6 years have produced seeds, but trees in dense natural stands are usually much older (25 years) before large crops are evident (Briscoe 1969; Wells and Schmidtling 1990). Fruit heads persist on the trees through the winter and break up the following spring. The hairy tufts at the base of the fruits act as parachutes for dissemination by wind. Sycamore fruits float easily and are therefore widely distributed by moving water (Wells and Schmidtling 1990).

Collection of fruits. Fruit heads of sycamore can be collected any time after they turn brown, but the job is easiest if done after leaf-fall. Because the heads are persistent, collections can be made into the next spring, usually making sycamore the last fall-maturing species to be collected in the East. This additional time on the tree after full maturity apparently does not harm seed quality (Briscoe 1969). Picking fruit heads by hand from the tree is the most common method of collection. At the northern and western limits of the range of sycamore, intact heads can sometimes be collected from the ground late in the season. As fruit heads begin to fall apart in the early spring, the seeds may sometimes be shaken loose by tapping the branches (Briscoe 1969). Once collected, fruit heads should be spread in single layers and dried in well-ventilated trays until they can be broken apart, no matter how dry they look at collection. This step is essential with fruit heads collected early in the season, as their moisture contents can be as high as 70% (Bonner 1972b).

Figure 1—*Platanus*, sycamore: fruiting heads of *P. occidentalis*, American sycamore (**top**) and *P. racemosa*, California sycamore (**bottom**).

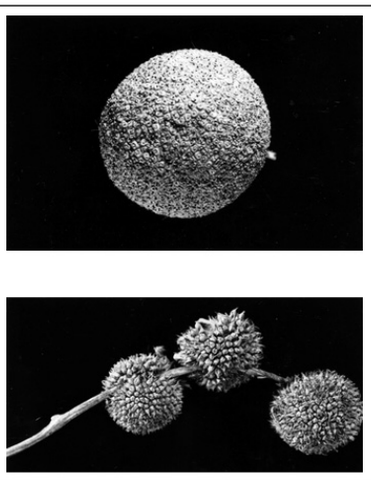


Figure 2—*Platanus*, sycamore: single achenes of *P. occidentalis*, American sycamore (**top**) and *P. racemosa*, California sycamore (**bottom**).

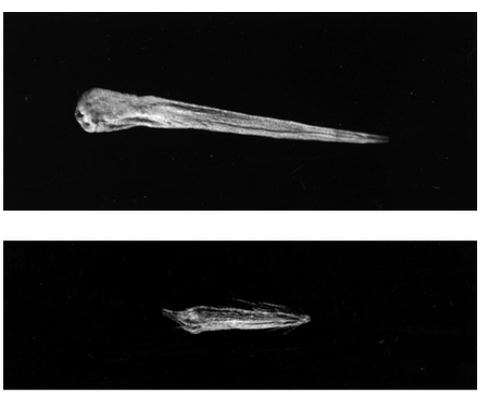
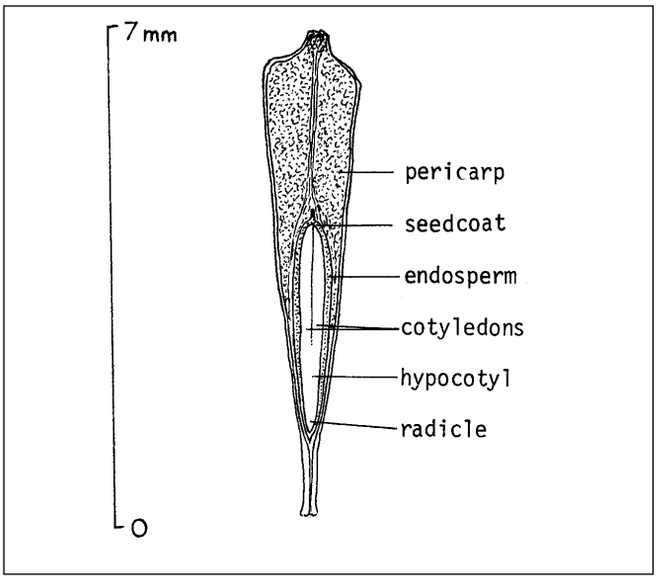


Figure 3—*Platanus occidentalis*, American sycamore: longitudinal section through a seed.



Extraction and cleaning of seeds. Seeds should be extracted by crushing the dried fruit heads and removing the dust and fine hairs that are attached to the individual achenes. Small lots can be broken up in small mechanical scarifiers or by hand-rubbing through hardware cloth (2 to 4 wires/cm) (Briscoe 1969). Medium-sized lots of up to 2 hl can be quickly broken up in mechanical macerators. Larger lots can be broken up in fertilizer distributors, hammermills, or centrifugal disks (Briscoe 1969; Bonner 1979). No matter which method is used, some method of dust removal should be provided and dust masks should be worn by workers! The fine hairs that are dislodged during extraction and cleaning are a danger to respiratory systems. The fertilizer distributor method is widely used, and the dust problem is

lessened when the operation is carried out in the open. The distributor can be loaded with fruits and pulled along with ejection gates closed, or a powered belt can be attached to a jacked-up wheel. With the jacked-up wheel arrangement, clean seeds will work out through the gates, while fruit cores and fluffs of the hairs will collect at the top.

Dust, fine hairs, and large trash can also be removed from seedlots with air-screen cleaners or aspirators. Studies with sycamore have shown that a 3 × 19 mm ($^{7}/_{64} \times {}^{3}/_{4}$ in) oblong-hole screen will remove twigs, leaves, and fruit cores, while dust, hairs, and small trash can be removed with 1.2 mm (1/21) round-hole screens (Bonner 1979). If the seedlot is especially trashy, 2 runs through the air-screen cleaner may be needed. The smaller cleaners can clean 5 to 7 kg of seeds/hour, and purities of greater than 99% are possible. Electrostatic seed cleaners can also do a good job cleaning sycamore. In a test by Karrfalt and Helmuth (1984), purity was increased from 88 to 99%. Louisiana and Mississippi collections of sycamore yielded 9 to 14 kg of seed/hl of fruitheads, and 55 to 66 kg of seeds/100 kg of fruitheads (Briscoe 1969). Some representative seed weight data for sycamore are listed in table 3.

Sycamore is noted for its low proportion of filled seeds, a condition due to poor cross-pollination and self-incompatibility in isolated trees (Beland and Jones 1967). Effective control of bed density in nurseries can be severely hampered by this condition, so upgrading of seedlots by mechanical means is highly desirable. Such operations are possible with gravity separators, aspirators, and electrostatic separators (Bonner 1979; Karrfalt and Helmuth 1984). For exmaple, a single pass on a gravity separator upgraded a sycamore seedlot from 27% filled seeds to 56% (Bonner and Switzer 1974).

Storage of seeds. Seeds of all sycamore species are orthodox in storage behavior and can be easily stored for long periods in cold, dry conditions. Storage tests with sycamore have shown that seed moisture contents of 5 to 10% and temperatures of 0 to 5 °C are suitable for short-term storage of up to 5 years. For longer storage periods, sub-freezing temperatures (–18 °C) at the same moisture content are recommended (Bonner 1979). The upper limit of storage potential for sycamore is not yet known, but current research suggests that it will be far beyond 10 years under optimum conditions (Bonner 1994). To maintain low seed moisture in moist surroundings, the dried seeds must be stored in moisture-proof containers, such as polyethylene bags or fiber drums with plastic liners (Bonner 1979). Several species of *Aspergillus* fungi have been identified as pathogens that harm viability of sycamore seeds in storage (Fakir and others 1971), but they have never been a major problem.

Pregermination treatments. Moist stratification for 60 to 90 days at 5 °C in sand, peat, or sandy loam has been reported as beneficial for germination of California sycamore (Bonner 1974). The other sycamores have no dormancy, and pregermination treatments are usually not required for prompt germination (Bonner 1972a; Webb and Farmer 1968). Germination rate of sycamore can be increased by treating with gibberellin (GA_3) at 100 to 1,000 mg/liter, but this increase seems to be simple growth stimulation that is not involved in seed dormancy (Bonner 1976).

Germination tests. Germination can be easily tested on wet paper or sand or even in shallow dishes of water (table 4). Official testing prescriptions call for alternating day/night temperatures of 30/20 °C on the top of moist blotters for 14 days (AOSA 1993). A large percentage of the sound seeds will usually germinate, but the great variation in number of sound seeds among lots will result in varied germination percentages. Surface sterilization of the seeds with a 30-second dip in a 1% commercial bleach solution is often beneficial to laboratory germination (Mullins 1976). Rapid viability tests can also be made on sycamore with tetrazolium staining and x-radiography (Bonner 1974).

Table 3—*Platanus,* sycamore: seed data

Species	Place of collection	Cleaned seeds/weight: Range /kg	Range /lb	Average /kg	Average /lb	Samples
P. occidentalis	Louisiana–Mississippi*	294,370–589,620	133,500–267,400	426,160	193,270	100+
	SE US	192,340–500,100	87,2330–226,800	330,530	149,900	28
P. orientalis	Denmark	178,600–357,200	81,000–162,000	282,240	128,000	8
	United States	249,160–370,440	113,000–168,000	308,700	140,000	2+

Sources: Bonner (1974), Briscoe (1969), Swingle (1939).

* Seedlots from these sources averaged 1,765 seeds/fruit (range from 804 to 3,050).

Nursery practice. Sycamores are usually sown in the spring by broadcasting or by mechanically drilling. For drilling, seeds should be placed no deeper than 3 mm ($^1/_8$ in) in rows 15 to 20 cm (6 to 8 in) apart. If sown on the surface of the beds, they should be covered with no more than 6 mm ($^1/_4$ in) of light mulch (Williams and Hanks 1976). Seedling density will depend on the intended use of the stock. For those wanting small seedlings, 110 seedlings/m^2 (10/ft^2) is recommended; for larger stock, 55/m^2 (5/ft^2) (Vande Linde 1960; Williams and Hanks 1976).

Bed surfaces must be kept moist through germination, and shading, while not necessary, can be helpful for the first month (Briscoe 1969; Engstrom and Stoeckler 1941). On neutral to slightly alkaline soils, damping-off may be a problem. Root pruning in midsummer is recommended to promote growth of smaller roots, and some nurseries prune seedling tops in late July or August to reduce size. Seedlings should not be both root- and top-pruned during the growing season (Briscoe 1969). Sycamore is usually outplanted as 1+0 stock, and oriental planetree is often planted as 1+1 or 2+0 seedlings in Europe (Bonner 1974). The sycamores are easy to propagate vegetatively by dormant or greenwood cuttings (Dirr and Heuser 1987), and many plantations of sycamore have been established in the South by these techniques. Some tests show no difference in growth after 1 year between seedlings and cuttings (Garrett 1975).

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Cupressaceae—Cypress family

Platycladus orientalis (L.) Franco

oriental arborvitae

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Synonym. *Thuja orientalis* L., *T. acuta* Moench., *Platycladus stricta* Spach., *Biota orientalis* (L.) Endl.

Other common names. Chinese arborvitae, biota.

Growth habit, occurrence, and use. Oriental arborvitae is native to northern and western China and Korea (Vidakovic 1991). This species was previously included in the genus *Thuja* (Schopmeyer 1974), but it has now been placed in *Platycladus,* a monotypic genus. It is a medium-sized tree (approximately 12 m tall) that is widely cultivated as an ornamental in the United States. Many ornamental cultivars have been developed (Dirr and Heuser 1987; LHBH 1976). The foliage of oriental arborvitae is not as aromatic as that of *Thuja* species, and its cones are rather fleshy (Rushforth 1987). It can be planted in many different soils and will tolerate drier soils than northern white-cedar—*Thuja occidentalis* L. Oriental arborvitae should be restricted to regions where the minimum temperature is above –24 °C (Rushforth 1987).

Flowering and fruiting. Flowering occurs in the spring, and the cones mature in the fall of the same year. The cones range from 1.5 to 2.5 cm in length and typically have 4 fertile scales. The seeds are dark reddish purple and wingless (figures 1 and 2) (Schopmeyer 1974).

Extraction, cleaning, and storage of seeds. Cones are usually collected by hand from the branches after they turn yellow or brown but before they open. Cones will open partially with only air-drying in the sun or inside at room temperature, but auxiliary heating is needed for complete extraction. Most cones should open in 24 to 36 hours when heated at 30 °C (Dirr and Heuser 1987). Seeds can be shaken from the cones with small cone tumblers or similar devices, then scales and trash can be removed with screens or seed blowers. If large numbers of empty seeds are present, seedlots can be upgraded with the careful use of seed blowers. Oriental arborvitae seeds range from 44,100 to 55,125/kg (20,000 to 25,000/lb) (Schopmeyer 1974).

Figure 1—*Platycladus* orientalis, oriental arborvitae: seeds.

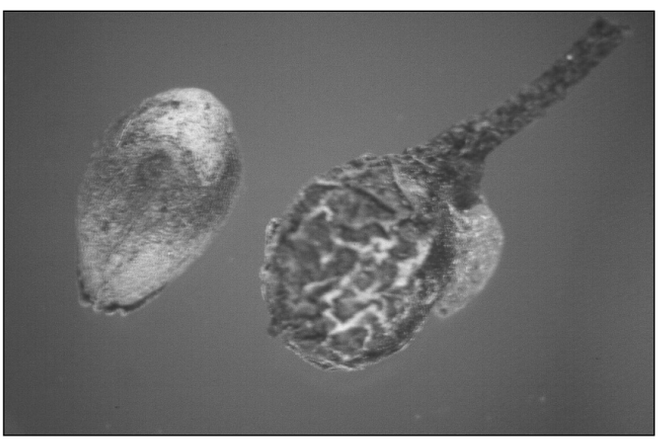
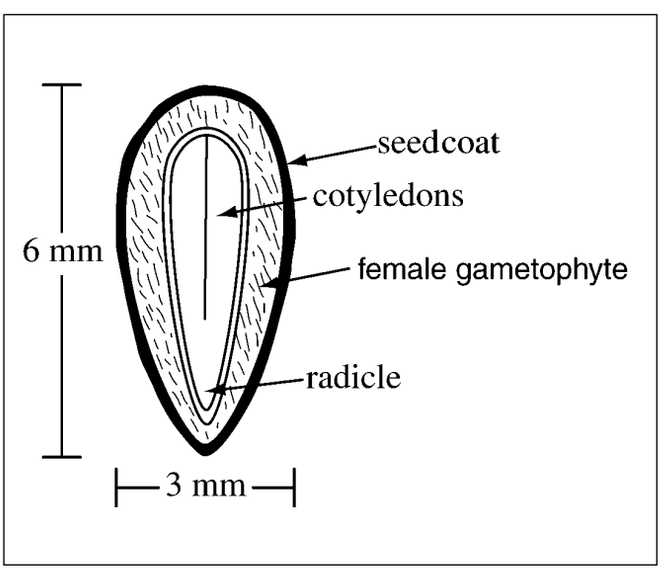


Figure 2—*Platycladus orientalis*, oriental arborvitae: longitudinal section through a seed.



Seeds of this species are orthodox in storage behavior. If dried to moisture contents of 5 to 10% and stored at near-freezing (0 to 5 °C) temperatures, viability should be main-

tained for at least 5 years. For longer storage periods, subfreezing temperatures of about –18 °C are recommended (Bonner 1991).

Germination tests. For most seedlots, pretreatments are not needed for germination tests, although beneficial effects have been reported for cold stratification for 1 to 1 $^1/_2$ months and for short soaks in weak solutions of gibberellic acid (Dirr and Heuser 1987; Schopmeyer 1974). Both AOSA (1993) and ISTA (1993) recommend testing oriental arborvitae on the top of moist paper media at a constant 20 °C for 21 days; no pretreatments are prescribed. Germination is epigeal.

Nursery practice. Sowing outdoor nursery beds should take place in the spring at a depth of 6 to 9 mm ($^1/_4$ to $^3/_8$ in) and no mulch. A bed density of 375 to 430/m^2 (35 to 40/ft^2) has been recommended (Schopmeyer 1974). Under most conditions, seedlings are grown for 2 years before outplanting, although this may vary according to individual nursery practices. Container production in greenhouses is also possible, using techniques that are successful with the closely related *Thuja* species.

Vegetative reproduction, while more difficult than it is with *Thuja* species, is possible with oriental arborvitae and is widely used for ornamental cultivars. Dirr and Heuser (1987) recommend taking cuttings from June to August, treating with indole-butyric acid (IBA) in talc and Benlate®, then rooting with mist and bottom heat in a peat and perlite mixture (2:1, v/v).

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Salicaceae—Willow family

Populus L.

poplar, cottonwood, aspen

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Growth habit, occurrence, and use. The Salicaceae, the family that includes poplars, cottonwoods, and aspens (*Populus* spp.) and willows (*Salix* spp.), is the most widespread group of woody plants in North America. The poplar genus—*Populus*—is subdivided into 5 sections (Aigeros, Leucoides, Leuce, Tacamahaca, and Turanga) and comprises 30 species, under the common names of poplar, cottonwood, and aspen. The taxonomy of the genus is complex because natural variation and hybridization are common among some sympatric species. In addition, species have been introduced from Europe, and both planned and natural hybrids have been produced for use in forestry and horticulture (Barnes 1961; Brayshaw 1966; Ceulemans 1990; Dickmann and Stuart 1983; Eckenwalder 1977, 1980; Einspahr and Benson 1964; Little and others 1957; Pregitzer and Barnes 1980; Rehder 1940; Schreiner and Stout 1934; Spies and Barnes 1982; Stettler and others 1996; Viereck and Foote 1970). The nomenclature and occurrence of the North American species and some of the exotic species and cultivars are presented in table 1. A thorough coverage of the nomenclature, distribution, genetics, evolution, hybridization, biology, and ecology of the genus can be found in Burns and Honkala (1990), Ceulemans (1990), Dickmann and Stuart (1983), Dickmann and others (2001), Einspahr and Winton (1977), FAO (1980), Hyun and others (1984), Schreiner (1971), Smith (1943), Stettler and others (1996), and Stout and Schreiner (1933).

The genus is wide ranging in North America (Burns and Honkala 1990). There are some unique aspects to the distribution of the poplar genus. Balsam poplar has the northernmost (and westernmost) range of any tree in North America, as it grows in the foothills transition from the Brooks Range to the Arctic coastal plain in northern Alaska and in the Mackenzie River delta in the Yukon (Viereck and Little 1972). These northernmost stands are associated with riparian areas. The distribution of poplar species within their natural ranges varies considerably. Quaking aspen, which has the most widespread range of any North American tree species, can form large monospecific stands of 40 to 50 ha consisting of only one clone. In fact, an aspen clone in Colorado is reputed to be the largest living organism known (Mitton and Grant 1996). Quaking aspen clones in the Great Lakes region, Alaska, and adjacent Canadian provinces, however, are generally small, seldom greater than .03 to 1.5 ha (Barnes 1966, 1969; Kemperman 1976; Kemperman and Barnes 1976; Parkerson 1977; Steneker 1973). Aspen in pure and mixed stands covers thousands of hectares in north temperate and boreal forests. Although some poplar species may have fairly large geographic ranges, they are restricted in occurrence and often exhibit their best development in (or are restricted to) riparian areas. Plains cottonwood, for example, occurs primarily in riparian areas in the Great Plains and occupies little of the dry upland area (Burns and Honkala 1990; Friedman and others 1997; Rood and others 1995; Stromberg 1993).

Species of the poplar genus occur mainly in early successional plant communities. They can quickly colonize after natural or human disturbances and grow rapidly where light, exposed mineral soil, and moisture are readily available. Depending on the species and site, they are usually replaced by more shade-tolerant species in 60 to 100 years. However, stands of some species have remained intact for more than 200 years in boreal forest environments in the Rocky Mountains. In areas with fire return intervals of 50 to 100 years, single clones of a species like aspen may persist for many centuries or, as some theorize, thousands of years (Barnes 1966; Burns and Honkala 1990; Mitton and Grant 1996). Although poplars are often viewed as being replaced by more tolerant trees, stands in the western Great Plains are replaced by grassland communities if they are not disturbed by periodic flooding (Friedman and others 1997).

Utilization and value of the genus can be considered in relation to their use in intensive culture and agroforestry plantations and in naturally occurring forests. Natural stands

Table 1—*Populus,* poplar, cottonwood, aspen: nomenclature and occurrence

Scientific name & synonym(s)	Common name(s)	Occurrence
***P. x acuminata* Rydb. (pro sp.)** *P. accuminata* var. *rehderi* (Sarg.)	**lanceleaf cottonwood,** lanceleaf poplar, smooth-bark cottonwood, & Andrews poplar	S Alberta, Montana, W North Dakota, Wyoming, W Nebraska, E Colorado, & New Mexico
***P. alba* L.**	**white poplar**, abele	Central & S Europe to W Siberia & Central Asia
***P. angustifolia* James**	**narrowleaf cottonwood,** narrowleaf poplar, black cottonwood, mountain cottonwood, *álamo*	S Saskatchewan & Alberta S to Arizona, W Nebraska, & trans-Pecos Texas; also in N Mexico (Chihuahua)
***P. balsamifera* L.**	**balsam poplar,** tacamahac poplar, cottonwood, hackmatack, tacamahac	Alaska to Labrador, S to New York & Oregon
***P. balsamifera* L. spp. *trichocarpa* (Torr. & Gray ex Hook.) Brayshaw** *P. trichocarpa* Torr. & Gray	**black cottonwood**, California poplar, cottonwood, balsam cottonwood, western balsam poplar	S Alaska & S Yukon to S California & W Nevada; local in Wyoming, SW North Dakota, & Lower California
***P.* x *canescens* (Ait.) Sm. (pro sp.)**	**gray poplar**	Europe & W Asia
***P. deltoides* Bartr. ex Marsh.**	**eastern cottonwood**, eastern poplar	Quebec to North Dakota, S to Texas & Florida
***P. deltoides* Bartr. ex Marsh. ssp. *monilifera* (Ait.)** *P. deltoides* var. *occidentalis* Ryb.	**plains cottonwood,** plains poplar, cottonwood, Texas cottonwood	SW Utah, Nevada, to N California, S to Arizona & New Mexico, NW Mexico
***P. deltoides* Bartr. ex Marsh. ssp. *wislizeni* S. Wats.** *P. fremontii* var. *wislizeni* S. Wats.	**Rio Grande cottonwood**, Rio Grande poplar, cottonwood, valley cottonwood, Wislizenus cottonwood, álamo	S Colorado, S Utah, New Mexico, W Texas, & N Mexico
***P. euphratica* Olivier**	**Euphrates poplar**, bahan, Gharab-Palk-Saf-Saf	Spain & W Morocco to Kenya, E to Central Asia
***P. fremontii* S. Wats.**	**Fremont cottonwood**, Fremont poplar, cottonwood, Arizona cottonwood, Macdougal cottonwood, *álamo*	SW Utah, Nevada, to N California, S to Arizona & New Mexico, NW Mexico
***P. grandidentata* Michx.**	**bigtooth aspen**, largetooth aspen, aspen, poplar, popple	Nova Scotia to NE North Dakota, S to Iowa & Pennsylvania, & along Appalachian Mtns to North Carolina
***P. heterophylla* L.**	**swamp cottonwood,** swamp poplar, cottonwood, black cottonwood, river cottonwood, downy poplar	Coastal plain from Connecticut & SE New York to Georgia & NW Florida, W to Louisiana, N in Mississippi Valley to Indiana, Ohio, & S Michigan
***P. laurifolia* Lebed.**	**laurel poplar**	Siberia
***P. maximowiczii* A. Henry**	**Japanese poplar**	NE Asia & Japan
***P. nigra* L.**	**black poplar**, European black poplar	Europe & W Asia
***P.* x *petrowskiana* R.I. Schrod. ex Regel**	**Petrowsky poplar,** Russian poplar	Europe
***P. sieboldii* Miq.**	**Siebold aspen,** Japanese aspen	Japan
***P. simonii* Carriere**	**Simon poplar**	NW China to Korea
***P. tremula* L.**	**European aspen**, tremble, Zitterpappel	Europe, North Africa, & NE Asia
***P. tremuloides* Michx.**	**quaking aspen**, quaking asp, aspen, golden aspen, mountain aspen, trembling aspen, Vancouver aspen poplar, popple, *alamo blanco*	Labrador to Alaska, S to Pennsylvania, Missouri, N Mexico, & Lower California

Source: Schreiner (1974).

of aspen, in particular, but other species too, are the basis for the pulp and paper industry in the north central United States and western Canada (Einspahr and Wyckoff 1990). Their ability to rapidly reoccupy a site by root suckering following harvest makes management of the species relatively easy. There is essentially no regeneration cost provided that care is taken to protect the root system of the harvested stand. Poplars have provided lumber for various uses and are important in the manufacture of reconstituted board products. Throughout human association with these species, virtually every part of the tree has been used for purposes that range from medicines to livestock feed to providing bark for carving art objects. Pure and mixed forests are important wildlife habitat. In the Great Plains areas of the

western United States and Canada, where they are the only tree cover, cottonwoods provide critical habitat for some species (Friedman and others 1997; Rood and others 1995; Stromberg 1993). They provide bark and male flowerbuds for specialist species such as beaver (*Castor canadensis*) and ruffed grouse (*Bonasa umbellus*) as well as forage for generalist browsers such as moose (*Alcea alcea*), elk (*Cervus elaphus*), and deer (*Odocoileus* spp.) (Burns and Honkala 1990; Dickmann and Stuart 1983; Dickmann and others 2001; Graham and others 1963; MacKinnon and others 1992; Peterson and Peterson 1995; Viereck 1987).

Poplars have long been important as ornamentals and in horticulture (tables 1 and 2). They were commonly used for amenity plantings in urban areas as ornamentals and landscaping. In rural areas, they have been used in shelterbelts and as ornamentals. The most rapidly increasing use of the species today is in intensive culture for wood fiber and biomass for energy in such diverse climates as the lower Mississippi Valley, western and eastern Washington, and western Minnesota. Shortages of fiber due to regulation of harvesting to protect critical wildlife habitat and old-growth forests, declining traditional forest land base, and concerns about effects of carbon dioxide (CO_2) from combustion of fossil fuels have renewed interest in intensive culture.

Poplars are ideal for short-rotation, intensive-culture management systems because (a) species and hybrids can be produced easily and propagated vegetatively, (b) juvenile growth is rapid, (c) response to cultural treatments is rapid, and (d) coppicing following harvest is prolific (Mitchell and others 1992; Stettler and others 1996). Poplar species are also readily propagated from tissue culture (Ostry and Ward 1991). Indeed, the first tree derived from tissue culture with both a shoot and attached root was a quaking aspen clone (Winton 1968a). Tree growth models are available for examining and predicting growth of poplar clones under different cultural regimes (Isebrands and others 1990; Stettler and others 1996).

In addition to classic tree breeding, advances have occurred due to the development of new genotypes using molecular genetics techniques (FAO 1980; Mitchell and others 1992; Stettler and others 1996).

Despite the large geographic range of the Salicaceae and the huge variation in growth form, there is remarkable uniformity in many aspects of the seed biology, dispersal, and germination. Thus information for willows, *Salix* spp. (Zasada and others 2005)—particularly those dispersing seeds during the summer—is relevant to poplar, *Populus* spp.

Table 2—*Populus,* poplar, cottonwood, aspen: height at maturity, first cultivation, minimum seed-bearing age, and seed crop frequency

Species	Height at maturity* (m)	Year first cultivated†	Minimum seed-bearing age (yr)	Years between large seedcrops
P. x acuminata	10.7–15.4 (18.5)	1898	5–10	1
P. alba	15.4–42.1	LC	10–15	—
P. angustifolia	10.7–15.4 (18.5)	1893	—	1
P. balsamifera	18.5–36.3	Before 1689	8–10	—
P. balsamifera spp. *trichocarpa*	15.4–61.5	1892	10	1
P. x canescens	29.2–30.8 (40)	LC	8–15	—
P. deltoides	24.6–58.5	Before 1750	10	1
spp. *monilifera*	12.3–30.8	1908	10	1
spp. *wislizeni*	2.3–30.8 (40)	1894	5	1
P. fremontii	15.4–30.8	1904	5–10	1
P. grandidentata	9.2–27.7 (30.8)	1772	10–20	4–5
P. heterophylla	24.6–27.3 (30.8)	1656	10	1
P. laurifolia	to 15.4	1830	8–10	—
P. maximowiczii	to 30.2	Before 1890	10	1
P. nigra	18.5–30.8	LC	8–12	1
P. simonii	to 12.3+	1862	10	—
P. tremula	21.5–38.5	LC	8–10	4.5
P. tremuloides	15.4–27.7 (30.8)	1812	10–20	4–5

Source: Schreiner (1974).

* Figures in parentheses indicate occasional heights on favorable sites.

† LC=long cultivated.

Flowering and fruiting. Poplars are mostly dioecious (Rehder 1940); but *P. lasiocarpa* Oliver (from China) has been described as a monoecious, self-fertilizing species (FAO 1980). Deviations from strict dioecism have been found in individual trees and catkins (Einspahr 1960a; Lester 1961, 1963; Maini and Coupland 1964; Pauley 1950; Pauley and Mennel 1957; Santamour 1956; Stettler 1971; Spies 1978). In addition, Santamour (1956), Pauley and Mennel (1957), and Lester (1963) reported that quaking aspen had bisexual frequencies of 7, 8.7 and 38%, respectively, and that hermaphroditism was higher among females (10.7, 20.6, and 32.3%) than among males (5.1, 4, and 27.4%). Stettler (1971) reported variation in sex expression among females of black cottonwood but not among males. Year-to-year variation in the frequency of abnormal flowers among individual trees was also reported.

Sex ratios in natural populations are not well-documented in the genus but appear to be male-dominated or equal, at least for quaking aspen (Einspahr 1960b; Einspahr and Benson 1971; Farmer 1964b; Grant and Mitton 1979; Lester 1963; Mitton and Grant 1996 ;Valentine 1975). Grant and Mitton (1979) and Comtois and others (1986) reported that sex ratios in quaking aspen and balsam poplar, respectively, were 1:1 on a regional or landscape basis, but the sexes seemed to be segregated to some extent within the regions studied. Grant and Mitton (1979) found that male quaking aspen trees were more common at higher elevations than females and that male balsam poplar trees tended to be more common on relatively drier and less fertile sites (Comtois and others 1986). Sex ratio reports have been criticized because of the biased sampling technique used in many of the studies. Generally, only flowering trees were sampled. Einspahr (1960b) attempted to eliminate this bias by girdling non-flowering trees within the sample population and returning to record sex the following year. Einspahr and Benson (1971) and Valentine (1975) also recorded the sex of individual trees within test plantings of quaking aspen over a period of years and thus observed flowering over enough years to determine the sex of all individuals in a population.

Aspen ramet growth rate and density, clone size, and rate of clone expansion appear to differ among male and female clones, with female clones surpassing males in the characteristics studied (Mitton and Grant 1996). Farmer (1964b) did not find differences among male and female trees in eastern cottonwood.

Age of first flowering shows considerable inter- and intraspecific variation (table 2). Cottonwoods and balsam poplars generally reach flowering age at 10 to 15 years. Usually, few seeds can be collected from plains and eastern cottonwood trees that are less than 10 inches in diameter or less than 10 years old (Maisenhelder 1951). Precocious flowering of seedlings a few months after germination has been observed in the poplar genus, but it is difficult to keep young seedlings alive to produce mature seeds (Riemenschneider 1996). Genetically engineered aspen that flower within months after germination have been developed (Weigel and Nilsson 1995).

Flowering and seed maturation differ within and among individual species (table 3). For example, aspen in the north temperate and boreal forests flowers in April or early May and seeds begin to disperse 4 to 6 weeks after flowering and finish in a few weeks. Winton (1968b) examined quaking aspen and eastern cottonwood fertilization under greenhouse and growth chamber conditions. Quaking aspen pollen germinated 6.5 hours after pollination and fertilization occurred after 8 to 72 hours, depending upon temperature. At 25 °C, aspen seeds mature in about 2 weeks in a controlled environment (Fechner 1972) and in 3 to 4 weeks in an environment with more variable temperatures (Brown 1989; Wyckoff 1975). By contrast, cottonwood in the lower Mississippi Valley flowers from March to early April; maximum dispersal of seeds occurs 8 to 10 weeks after flowering, with some dispersal occurring after 16 weeks (Farmer 1964a, 1966). In a controlled environment, viable cottonwood seeds are obtained in May to June following pollination in late February to early March (Farmer and Nance 1968). Cottonwood fertilization occurred between 24 to 72 hours after pollination.

Within these general flowering and dispersal patterns, there is significant variation among trees in local populations for most of the species studied. There are also observations of very early flowering and seed dispersal that are well outside the general ranges (table 3) attesting to the temperature controls over flowering. For example, Shafroth (1996) observed flowering in Fremont cottonwood in January and seed dispersal by mid-late February. Quaking aspen flowers have broken bud during warm spells in mid-February in interior Alaska; subsequent temperatures of –30 to –40 °C arrested development, but it resumed with the onset of higher temperatures in April (Barnes 1961; Farmer 1966; Pregitzer and Barnes 1980; Spies and Barnes 1982). Flowering in hybrids may be intermediate between or similar to one of the parents (Pregitzer and Barnes 1980; Spies and Barnes 1982).

Interspecific crossing between desired species or intraspecific crossing of selected individuals of the same species in a controlled environment is a common practice in breeding poplars. The general steps in this process are sum-

Table 3—*Populus*, poplar, cottonwood, aspen: phenology of flowering and fruiting

Species	Location	Flowering	Seed ripening & dispersal
P. x *acuminata*	Nebraska	May	July
P. alba	Nebraska	Apr–May	Early June
	NE US	Apr–May	May–June
	S Michigan	Mar–Apr	May–June
P. balsamifera	Alberta	Late Apr	Early June–early July
	Lake States	Apr–May	May–June
	Interior Alaska	May–June	July
P. balsamifera spp. *trichocarpa*	Vancouver Island, British Columbia	Apr–June	Late May–mid-July
P. x *canescens*	Great Lakes region	Late Apr	Late May
P. deltoides	Lower Mississippi Valley	Early Mar–early Apr	Mid-May–late Aug
	NE US	Apr–early May	May–mid-June
spp. monilifera	Alberta	—	late June–early Aug
	Lincoln, Nebraska	Apr–May	June
spp. *wislizeni*	Albuquerque, New Mexico	Apr–May	June–July
P. fremontii	Central Arizona	mid-Feb–mid-Mar	Mar–Apr
P. grandidentata	Syracuse, New York	Mid-Mar–mid-Apr	Mid-May–late May
	S Michigan	Late Mar–min-May	early May–late June
	New England	Mid-Mar–Apr	May–early June
	N Great Lakes region	Late Apr–early May	Late May–early June
P. heterophylla	Mississippi	Mar–May	Apr–July
P. maximowiczii	Rochester, New York	Late Apr	Aug
P. nigra	Rochester. New York	Apr	Late May
P. tremula	N Great Lakes region	Mid-Apr	Mid-May
P. tremuloides	Great Lakes region	Late Mar–early May	Mid-May–mid-June
	Alberta, Canada	Early Apr–early May	Mid-May–mid-June
	New England	Mid-Mar–Apr	May–early June
	Interior Alaska	Apr–May	Late May–early June
P. tremula	N Great Lakes region	Mid-Apr	Mid-May

Sources: Johnson (1990); Schreiner (1974).

marized below, but for more detail refer to Einspahr and Benson (1964), Farmer and Nance (1968), Gladysz (1983), Johnson (1945), Larsson (1975), Stanton and Villar (1996), Stettler and others (1980, 1996), Wettstein (1933), and Wyckoff (1975).

- Branches with flower buds are collected from male clones in late winter after cold requirements for dormancy have been satisfied. The branches are incubated in a controlled environment in water-filled containers. (Water should be changed 2 to 3 times per week. Before branches are placed in water and each time the water is changed, their ends should be recut. This removes 1 to 2 cm of wood and exposes fresh xylem to maintain water uptake.) Pollen is usually produced in 1 to 2 weeks, depending on species and temperature conditions. Pollen can be collected and stored in a desiccator for 1 to 2 months at about 0 to 1 °C and low humidity. For longer storage, the pollen should be kept under vacuum at –20 °C according to the procedure described by Hermann (1969).
- Branches or grafted material from female clones are brought into a controlled environment after cold requirements have been satisfied. This is usually timed to be several days after male branches are collected or after pollen has been extracted. The best length for cut branches is about 1 m. The cut stems are treated as described above for male branches. Alternatively, grafted or rooted cuttings have been recommended for species with large catkins or with longer flowering and seed maturation periods such as occur in eastern cottonwood.
- As the female flowers begin to elongate, pollen is applied with a brush or atomizer. Pollen is sometimes applied to flowers over several days to ensure good pollination and seed yield. Small quantities of viable, select pollen are often mixed with heat-killed pollen to extend the amount available. To make crosses between individuals with poor compatibility, irradiated or otherwise sterile pollen (mentor pollen) from a compatible source is mixed with the desired viable pollen (Stettler and Guries 1976). It may be necessary to remove a sig-

nificant number of flowers from the branches in order to ensure enough water, nutrition, and carbohydrate for full development of a limited number of catkins. Cooler greenhouse temperatures (15 to 21 °C) are better than warmer temperatures. Seeds are collected as the ripened capsules open. *In vitro* embryo culture has also been used in hybrid breeding programs where seed yield is low or non-existant.

An individual eastern cottonwood tree, measured to be 12.3 m in height with a stem diameter of 0.6 m and a crown spread of 13.8 m, bore about 32,400 catkins. These produced about 27 capsules per catkin and about 32 seeds per capsule. The average weight of 100 seeds (with cotton) was 0.065 g. On this basis, it was estimated that this tree produced nearly 28 million seeds, weighing about 18.2 kg (Bessey 1904). Aspen species also produce seeds in large quantities. Reim (1929) reported the following estimates of seed production for sample trees of European aspen in Estonia and Finland:

Age of tree (yr)	Catkins (no.)	Seeds (no.)
8	9	8,700
25	1,200	1,275,000
25	500	205,000
45	10,000	3,300,000
100	40,000	54,000,000

Although poplar seeds seem to be available each year, there have been few studies thoroughly documenting annual periodicity (Burns and Honkala 1990). Cottonwoods and balsam poplar (Figure 1) produce large seedcrops almost every year; aspens produce some seeds almost every year, and bumper crops are produced at intervals of 3 to 5 years. Six-year records for seed shedding by balsam and Petrowsky poplars in Alberta indicated an abundance of seeds in all years; aspen produced heavy seedcrops about 3 of every 7 years and comparatively little or no seeds in the other years (Moss 1938). During a 3-year period in interior Alaska, there was 1 excellent and 2 poor seedcrops (Zasada 1996).

Annual flowering records of 25- to 33-year-old quaking aspen clones (17 female and 16 male) established as grafts in a Wisconsin breeding arboretum indicated that the females flowered in 70% of the years of a 20- to 26-year period; males in 80% of the years and 2 bisexual clones in 78% of the years. (Note: these clones were randomly selected based on superior phenotypic characteristics, with no prior knowledge of tree gender. The male to female ratio for this collection covering a wide geographic area was basically 1:1 and substantiates studies cited above.) Individual female clones flowered in as few as 41% and as high as 100% of the years; individual male clones flowered in as few as 55% and as high as 100% of the years. Males tended to flower more frequently than females, with 38% of the male clones flowering in at least 95% of the years compared to 18% of the female clones flowering in at least 95% of the years. Eleven grafted clones established in the arboretum flowered 1 year after planting. Years when widespread flowering occurred in a Wisconsin arboretum appeared to be related to below normal rainfall in May of the previous years (Wyckoff 1996).

One clone of quaking aspen was established in the same year as both grafts and rooted root sprouts. The grafted ramets flowered in 70% of the years in a 23-year period; the rooted ramets flowered in 4% of the those years (Wyckoff 1996).

Figure 1—*Populus balsamifera*, balsam poplar: tree at peak stage of seed dispersal.

Flowering of 24- to 36-year-old grafted clones of bigtooth aspen (3 female and 7 male) was also followed in the above-mentioned Wisconsin arboretum. The female clones flowered in 35% of the years in a 20- to 25-year observation period and the males in 18% of the years. Flowering of individual female clones occurred in from 29 to 40% of the years; male clones flowered in 0 to 50% of the years (Wyckoff 1996).

Mature catkins are made up of many capsules, each developed from an individual flower (figures 1 and 2). The number of viable seeds per capsule has been reported to vary from 2 to 7 for quaking aspen (Brown 1989; Henry and Barnes 1977; Nagaraj 1952; Spies 1978); 2 to 10 for bigtooth aspen (Henry and Barnes 1977); 2 to 4 for bigtooth–quaking aspen hybrids (Henry and Barnes 1977); about 1 for white poplar (Spies 1978); 1 to 2 for white poplar hybrids with bigtooth aspen (Spies 1978); and 8 to 15 (Nagaraj 1952), 32 (Bessey 1904), and 40 to 60 for eastern cottonwood (Farmer and Nance 1968). Estimates of seed production per catkin for quaking aspen have varied considerably among studies and locations: 500 in central Alberta (Brown 1989), 77 in northern Wisconsin (Rudolph 1978) 280 to 290 in southern Michigan, (Henry and Barnes 1977; Spies 1978), and 150 to 300 in central Wisconsin (Einspahr and Benson 1964). Henry and Barnes (1977) reported 500 seeds per catkin for bigtooth aspen. Spies (1978) reported about 11 seeds per catkin for white poplar, 281 for quaking aspen, and 102 for the hybrid P. × *rouleauiana* Boivin.

Figure 2—*Populus*, poplar: catkins consisting of mature but unopened capsules.—*P.deltoides* ssp. *monilifera*, plains cottonwood (**top**); *P. fremontii*, freemont cottonwood (**middle**); *P. freemontii* ssp. *wislizeni*, Rio Grande cottonwood (**bottom**).

The distance traveled by poplar seeds during primary dispersal equals or exceeds that for any tree species in North America. If seeds should land in a river, the distance of

secondary dispersal can also be great. Aspen seed rain and seedling establishment have been observed in significant quantities at distances of 5 to 10 km from the nearest seed source (Dyrness and others 1988; Zasada 1996; Zasada and Densmore 1979). Large quantities of seeds are deposited in the parent stand too. The dispersal unit—seed plus hairs, also referred to as "cotton" and "coma" (Fechner 1972; Fechner and others 1981; Roe and McCain 1962)—is very buoyant and ideally suited for both vertical and horizontal long distance movement by wind and air turbulence. The hairs are an outgrowth of epidermal cells of the ovule and are attached to the seed near the radicle (Fechner 1972). The deployment of these hairs has been described by Lautenschlager (1984) and Lautenschlager and Lautenschlager (1994) for Willow and briefly summarized by Zasada and others (2005).

Estimating seed rain in the Salicaceae is more difficult than in other trees because of the small size and short life of seeds and the type of dispersal unit. Water-filled seed traps and germination seed traps have proved useful (Walker and others 1986; Zasada 1996; Zasada and Densmore 1979), as have traps that use sticky substances. Water is a particularly good medium in which to catch seeds because once the dispersal unit lands on water it remains and because Salicaceae seeds germinate in water, allowing an assessment of viability.

A seed consists of an embryo surrounded by a thin transparent seedcoat. Seeds are very small, measuring but a few millimeters in length and width (figures 3, 4, and 5). There may be a rudimentary endosperm, but it apparently contributes nothing to the vigor of seeds during germination (Simak 1980). Nagaraj (1952) reports that the endosperm is completely consumed by the developing embryo in both quaking aspen and eastern cottonwood. The dry seeds tend to be tan to straw-colored in some species and green in others. Seed weights can vary substantially within a species and among sympatric species. For example, quaking aspen seeds were reported to weigh 0.127 g/1,000 seeds (223,200/oz) (Spies 1978), 0.133 g/1,000 seeds (212,000/oz) (Benson 1972), and 0.035 g/1,000 seeds (818,000/oz) (Henry and Barnes 1977) and bigtooth aspen, 0.091 g/1,000 seeds (312,000/oz), 0.093 g/1,000 seeds (306,000/oz), and 0.021 g/1,000 seeds (1,350,000/oz), respectively, for seeds of the 2 species collected in different years. The seed size of hybrids may be intermediate or smaller than that of their parents (Henry and Barnes 1977; Spies 1978). Tables 4 and

Figure 3—*Populus balsamifera*, balsam poplar: catkins in different stages of capsule opening. Capsules on the catkin in the foreground are unopened whereas those on the catkin in the background, and on the same branch as catkin in foreground, are fully opened and their cotton is fully expanded. The small dark dots in the cotton mass are individual seeds.

Figure 4—*Populus*, poplar: cleaned seeds of quaking aspen, *P. tremuloides* (**left**); cottonwood, *P. deltoides* (**center**); and bigtooth aspen, *P. grandidentata* (**right**); units on the scale at right are millimeters.

5 provide seed weight information for several poplar species and their hybrids (Wyckoff and Harder 1996). These seed weights are in agreement with other published information (Schreiner 1974) and support the reports of intermediate seed weight of hybrids. Section Leuce poplars tend to have smaller and lighter weight seeds than do species of other sections.

Collection, extraction, and cleaning of seeds. Seeds can be safely collected when a small percentage of capsules begin to open (Brown 1989; Fung and Hamel 1993; Johnson 1946; Maisenhelder 1951; Moss 1938; Wyckoff 1975). For aspen, it has been suggested that catkins should be picked from the trees when the seeds are a light straw color; those collected before reaching this stage do not ripen completely, reducing the yield of viable seeds (Brown 1989; Faust 1936). Branches with attached, immature catkins can be collected, placed in water, and ripened in a greenhouse. Seeds are collected as open capsules.

Care must be taken in handling catkins after they have been removed from the tree. They should be transported in a container, for example a large paper bag, that allows some air circulation and from which water can evaporate; this is particularly true if the catkins are to be kept in the container for several days during transport. For rapid drying, catkins should be spread out in thin layers in pans or on screens at room temperatures as soon as possible. Seeds will be shed in 1 to 5 days, depending on the ripeness of the catkin. Eastern cottonwood seeds also have been extracted by putting the ripe catkins through a standard seed macerator with the cylinder teeth 1.3 cm ($^1/_2$ inch) apart and running the macerated catkins over a clipper fanning mill (Engstrom 1948).

If the catkins are permitted to mature on cut branches in water culture, the seeds can be collected with a shop vacuum cleaner using a clean cloth bag substituted for the dust bag (Harder 1970; Roe and McCain 1962). Seeds from detached catkins spread out to dry in a thin layer can also be collected with this machine.

The most efficient method for freeing poplar seeds from the cotton is by tumbling them in a rotating drum or stream of relatively high pressure air. For small quantities of seeds, separation can be done by placing the seeds with cotton in a container over a nest of soil sieves or between 2 soil sieves and applying a stream of air at high velocity to tumble the seeds in the container. The seeds fall through to the lower screen of smaller sieve openings (Einspahr and Schlafke 1957; Fung and Hamel 1993; Roe and McCain 1962). Compressed air from any source or air from a vacuum cleaner exhaust can be used. Screen mesh size (openings per inch) will depend on seed size (table 4); a larger-seeded

Table 4—*Populus,* poplar, cottonwood, aspen: seed weights by soil sieve size (20 to 50 mesh)*

Species	Seeds (millions)/weight							
	20-mesh		28-mesh		40-mesh		50-mesh	
	/g	/oz	/g	/oz	/g	/oz	/g	/oz
P. alba	5.09	2.31	8.89	4.03	19.71	8.94	—	—
P. balsamifera	—	—	7.90	3.58	8.69	3.94	—	—
spp. *trichocarpa*	2.71	1.23	4.54	2.06	—	—	—	—
P. x *canescens*	—	—	7.50	3.40	13.87	6.29	—	—
P. deltoides	2.93	1.33	4.92	2.23	—	—	—	—
P. grandidentata	—	—	—	—	21.52	9.76	39.58	17.95
P. tremula	—	—	—	—	17.46	7.92	—	—
P. tremuloides	—	—	13.19	5.98	18.46	8.37	23.62	10.70
Some hybrid crosses†								
P tremuloides x P. tremula	—	—	10.61	4.81	17.68	8.02	38.68	17.54
P. tremula x P. tremuloides	—	—	18.43	8.36	44.10	20.00	—	—
P. tremuloides x P. canescens	—	—	—	—	16.27	7.38	—	—
P. canescens x P. tremuloides	—	—	7.74	3.51	13.38	6.07	35.57	16.13
P. grandidentata x P. alba	—	—	—	—	23.09	10.47	47.83	21.69
P. alba x P. grandidentata	4.81	2.18	10.52	4.77	15.79	7.16	35.10	15.92
P. grandidentata x P. canescens	—	—	—	—	19.45	8.82	30.96	14.04
P. canescens x P. grandidentata	—	—	7.08	3.21	10.36	4.70	31.00	14.06
P. deltoides x P. balsamifera	4.34	1.97	5.18	2.35	—	—	—	—
P. deltoides x P. nigra	4.43	2.01	6.90	3.13	60.86	27.60	—	—
P. deltoides x P. trichocarpa	3.00	1.36	4.54	2.06	—	—	—	—
P. trichocarpax P. balsamifera	3.20	1.45	4.83	2.19	—	—	—	—

Source: Wyckoff (1999).

* Sieve=standard soil screen sieve openings per square inch.

† In hybrid crosses, the female parent is listed first.

species, for example cottonwood, requires larger mesh screens (Einspahr and Schlafke 1957). Nests of sieves recommended for aspen are 20-, 28-, 40-, and 50-mesh soil screens from top to bottom (Harder 1970). Seeds were collected on the 40- and 50-mesh screens, with the best seeds on the 28- and 40-mesh screens for aspen and 20- to 28 mesh screens for cottonwood (Fung and Hamel 1993; Harder 1970; Rudolph 1978). Larger quantities of seeds may be cleaned efficiently in a rotating drum with or without a fan to blow the seeds through the wire seed screen; the cotton will remain in the drum. Small quantities of seeds can be separated from the cotton by rubbing them over a wire soil screen with suitably small mesh, by hand, or with a heavy brush (Faust 1936; Maisenhelder 1951). However, only about 20% of the seedlot can be extracted by this method (Maisenhelder 1951). Simak (1980) stresses that dried seeds can be brittle and damaged with rough handling during the extraction process.

Debris can be partially removed from poplar seedlots by carefully applying low-pressure air to seeds placed in a 500-ml Erlenmeyer flask held at a 30 to 45% angle. A highly efficient technique used routinely by the University of

Figure 5—*Populus*, poplar: longitudinal section through the embryo of a seed.

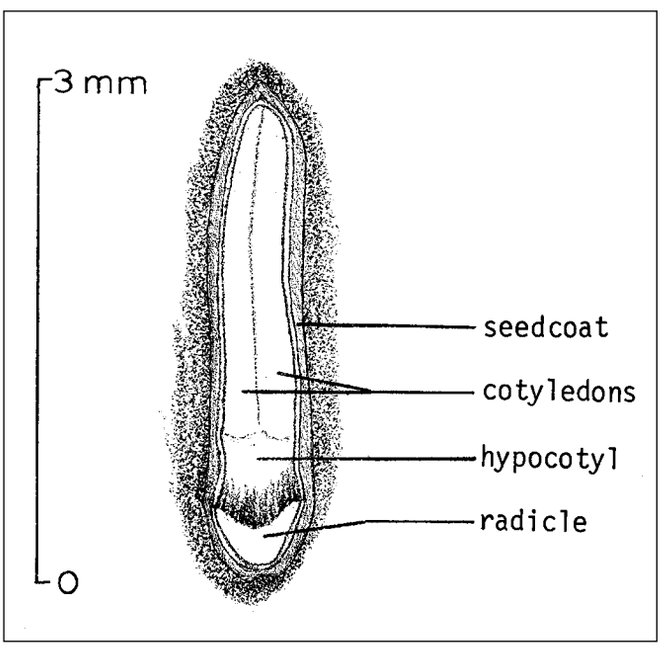


Table 5—*Populus*, poplar, cottonwood, aspen: seed weights of non-screened samples

Species	Seeds (x million)/weight				Samples
	Range		Average		
	/kg	/lb	kg	/lb	
P. deltoides	0.44–3.31	0.20–1.50	0.77	0.425	6+
P. deltoides spp. *monilifera*	0.55–1.06	0.25–0.48	—	—	4+
P. grandidentata	—	—	6.62	3.00	1
P. heterophylla	0.31–0.36	0.14–0.16	0.34	0.15	4
P. tremula	5.89–16.65	2.66–7.55	8.09	3.67	30
P. tremuloides	5.51–6.62	2.5–3.0	6.00	2.75	—

Source: adapted from Schreiner (1974).

Minnesota's Aspen and Larch Genetics Cooperative employs a vacuum seed sorter built after the one described by Edwards (1979). Seedlots cleaned by this technique are virtually free of contamination, an important consideration when seeds are to be sown mechanically in containers.

Storage of seeds. Under natural conditions, poplar seeds have been reported to maintain viability from 2 weeks to a month, varying with species, season, and microenvironment. There is some evidence that poplar seeds may have a longer lifespan under apparently adverse conditions such as in colder soils (Graham and others 1963; McDonough 1979; Moss 1938; Trappe 1964; Zasada and Densmore 1977).

Poplar seeds are one of the best examples of seeds with a short life-span (microbiotic seeds) among tree species. However, with proper drying and storage at subfreezing temperatures in sealed containers, the viability of seeds of eastern cottonwood (Tauer 1979, 1995; Wang 1982), and quaking and bigtooth aspen (Benson and Harder 1972, 1996; Wang 1982) have been maintained at fairly high levels for 10 to 12 years. Loss in viability during these relatively long storage periods varies among species and trees within species (Asakawa 1980; Benson and Harder unpublished data; Fechner and others 1981; Simak 1980; Tauer 1979, 1995; Wang 1982; Zasada and Densmore 1977, 1980). For example, Tauer (1995) found that percentage germination varied from 3 to 53% among individual trees after 12 years of storage, whereas initial germination ranged from 47 to 100%.

There is no single method of storage found to be generally acceptable for all species (Simak 1980). There are several elements that are important for maintaining long-term viability. Prestorage drying during capsule opening and immediately after extraction is essential for successful storage (Simak 1980). The desired moisture content for several species seems to lie between 6 and 10% (dry weight basis) (Simak 1980; Tauer 1979; Zasada and Densmore 1977, 1980), although Wang (1982) reported good long-term storage at 11 to 15% moisture content (dry-weight basis). Seed viability is maintained at lower moisture contents, but there is an indication that seedling vigor is reduced under these conditions (Simak 1980). Recommendations for drying time to achieve these approximate moisture contents have varied: for example, 2 to 3 days at 21 °C (Moss 1938); 3 to 8 days at 24 °C (Faust 1936); air-drying for 7 days (Tauer 1979); 1 day at 35 to 40 °C, and 1 day of drying over calcium chloride ($CaCl_2$) (Simak 1980). If achieving a specified moisture content is important, a method should be used that attains the desired content as quickly as possible while not affecting seed viability.

A number of research trials have compared storage under vacuum and with various desiccants to storage in sealed containers; unfortunately, the results are not definitive. In some cases, they work and in others they seem to be of no benefit or may even have a negative effect on viability.

Benson and Harder (1972) compared 4-year germination results from 40-mesh aspen and aspen hybrid seeds stored over calcium chloride in a desiccator at 4.4 °C and –24 °C. Freezer storage maintained higher levels of viability in each of the 4 years with the exception of 2 hybrids of bigtooth aspen during the first year. By year 4, all seedlots stored at 4.4 °C were either nonviable or had considerably reduced germination. Freezer-stored seeds maintained a high level of germinative ability at the end of 4 years, with the exception of gray poplar hybrids. Benson and Harder's study (1977, 1996) indicates that germination of freezer-stored seed of quaking aspen dropped from an average of 98% to 65% over a 10-year period. Hybrid seeds and 50-mesh seeds generally had lower germination than quaking aspen and 40-mesh seeds after 10 years of freezer storage. Seed viability of 3 of 4 open-pollinated cottonwood seedlots stored at –24 °C over calcium chloride did not decrease during 8 years of storage.

Hellum (1973) found that balsam poplar seedlots stored in sealed containers without desiccant at 7 °C and 21 to 24 °C rapidly lost viability after 130 days at both temperatures. Cold-stored seedlots retained viability longer (40 vs 5% at 200 days) but viability dropped to 5% at 245 days.

Simak (1980) reported that storage of European aspen seeds with a desiccant reduced viability because it dried seeds to a sub-optimal moisture content. Simak (1980) concluded that, when using desiccants, the desired moisture content of the seeds should be known and the type and quantity of desiccant should be selected to achieve the desired conditions. For example, seeds will equilibrate at the desired moisture content in an atmosphere of 10 to 30% relative humidity, and thus the desiccant should be selected that provides these conditions (Simak 1980). The optimum rate of drying is not known. Tauer (1979, 1995) reported that there was no difference in viability between cottonwood seeds stored with and without a vacuum at –22 °C after about 6 years. However, after 12 years, seeds from different families stored in a vacuum germinated at 10 to 99%, whereas those without vacuum germinated at 3 to 53%.

The one aspect of storage about which there seems to be no question is temperature conditions for long-term storage. Seeds should be extracted and placed in subfreezing storage as soon as possible. Seeds from boreal and Arctic species and those from warm climate species all seem to have the same general requirements. Temperatures from –5 to –24 °C seem acceptable and easy to achieve and maintain (Benson and Harder 1972; Fechner and others 1981; Moss 1938; Simak 1980; Tauer 1979; Wang 1982; Zasada and Densmore 1977, 1980). Seeds can be stored at 0 to 5 °C, but longevity is shorter and high levels of abnormal germination may occur sooner than at sub-freezing temperatures.

Germination tests. The criteria used to define germination are important when evaluating germination in the Salicaceae. The standards proposed by Simak (1980) for *Salix* and *Populus* germination provide a basis for assessing germination (figure 6). The work of Simak (1980) illustrates convincingly that use of criteria that do not include all of the stages leading up to appearance of a "normal" seedling may be suspect. Development of the hypocotyl hairs—or "coronet" as described by Fechner and others (1981)—and attachment of these hairs to the substrate is a departure from the usual pattern of epigeal germination (other species do not have these specialized hairs) and should be an assessment criteria for germination. The average time elapsed to achieve the various stages of development under greenhouse conditions are shown in figure 6; they will, however, vary depending on temperature and water availability (McDonough 1979; Schreiner 1974; Simak 1980).

Poplar seeds do not exhibit dormancy; they germinate at temperatures ranging from 2 to 40 °C (figure 7). Simak (1980) provides a thorough description of abnormal germination in Salicaceae. Average time required for aspen seeds to achieve various stages of germination under greenhouse conditions are indicated in hours and days (Wyckoff 1996). Optimum temperatures for germination may vary with species and possibly within widely distributed species like quaking aspen, but they appear to be in the range of 20 to 30 °C. Germination rate increases with temperature but appears to be fairly uniform above 15 to 20 °C and may decline slightly above 30 to 35 °C (figure 7). Temperatures above 35 °C caused a large decline in germination in aspen but had little effect on eastern cottonwood (Farmer and Bonner 1967; Faust 1936; Moss 1938; McDonough 1979; Zasada and Densmore 1980; Zasada and Viereck 1975). Seeds germinate fully in complete darkness, but rate of germination may be less than in light (Asakawa 1980; McDonough 1979).

Germination occurs on a wide variety of substrates. Some *Populus* species appear to have fairly exacting requirements for germination whereas others are less affected. Substrates with a steady supply of water during germination and early seedling development and a neutral or slightly acidic to slightly basic pH provide conditions for maximum germination (Dickmann and Stuart 1983; Farmer and Bonner 1967; Faust 1936; Fechner and others 1981; McDonough 1979; Segelquist and others 1993). Seeds germinate while floating in water or when fully submerged (Hosner 1957; Krasny and others 1988). Substrates with high salt concentrations appear to reduce germination potential (Faust 1936; Krasny and others 1988; McDonough 1979; Shafroth and others 1995).

At the University of Minnesota's Aspen and Larch Genetics Cooperative, seeds are germinated on damp filter paper in petri dishes for viability checks. However, for estimates of germination and vigor of seedlots to be used in nursery beds and containers, seeds are sown in clay saucers filled with commercial soil-less mix. This technique is more important for seedlots with germination less than 70 to 80% because it gives a more accurate prediction of cell occupancy in containers and seedlings per area in seedbeds (Wyckoff 1996).

Aspects of germination outlined above apply to newly collected seeds. Results may vary for the following reasons:

- Seeds stored for varying lengths of time may germinate slowly and exhibit poorer germination than would be

Figure 6—*Populus*, poplar: stages in the normal germination of a seed (adapted from Simak (1980) and McDonough (1979).

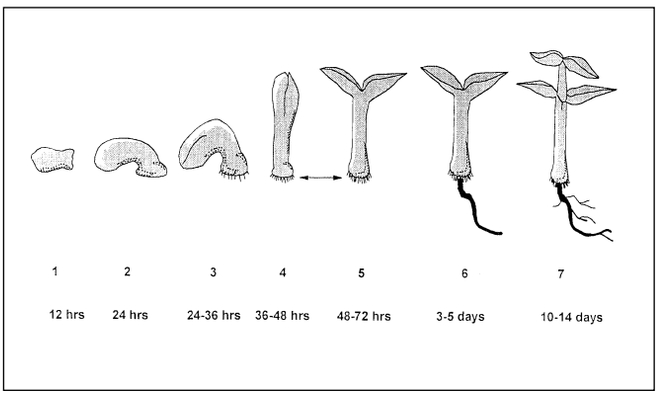
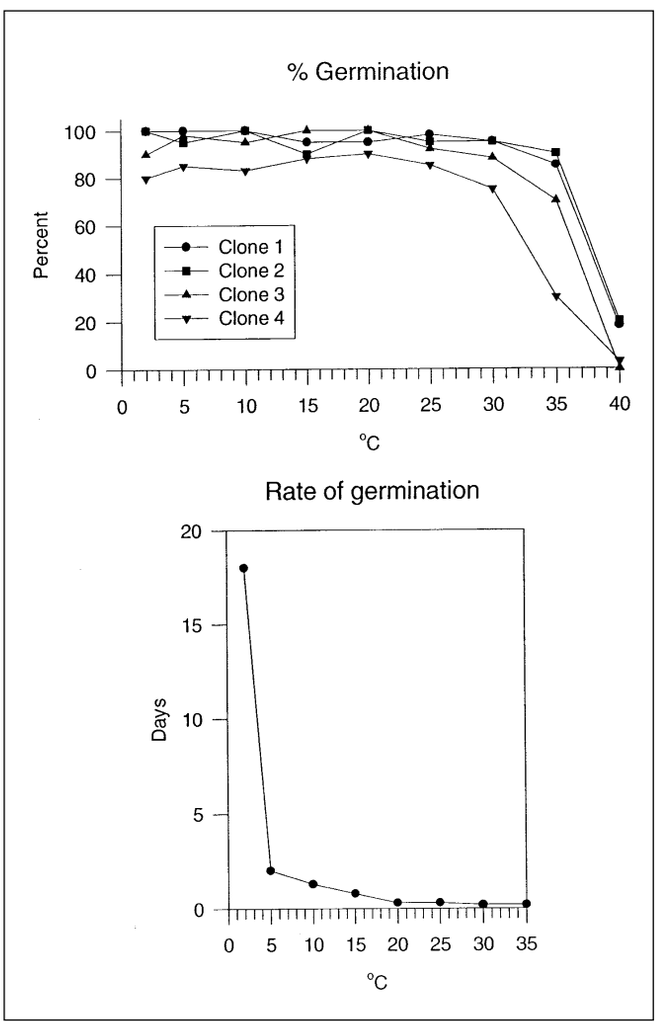


Figure 7—*Populus tremuloides*, quaking aspen: effects of temperature on percentage germination and germination rate in seeds (from McDonough 1979); rate is expressed as time for 10% of seeds to germinate.



expected for fresh seeds; this may be particularly true when germinating outside the optimum temperature range (Farmer and Bonner 1967; McDonough 1979).

- Small seeds may not germinate as well as large seeds. For example, Faust (1936) found that seeds graded to a 40-mesh soil screen showed a germination percentage of less than half that of seeds graded to a 30-mesh soil screen. The same relation holds true for seeds from 40- and 50-mesh soil screens (Rudolph 1978).
- Germination of stored seeds of white poplar was reduced due to too rapid imbibition of water (Polya 1961).

Seed testing rules (ISTA 1993) recommend that germination tests consist of four 100-seed replications and that tests be conducted at temperatures between 20 and 30 °C, with initial counts after 3 days. The results of the research summarized above suggest that using temperatures of 20 to 25 °C might be best for all seeds, including those tested following storage. Because of the rapid rate of germination and germinant development, there will be instances where evaluation would be desirable after 1 or 2 days, particularly when comparing germination rates of stored vs. newly collected seeds. Earlier versions of seed testing rules (ISTA 1966) called for using 0.25 g of seeds per replicate. Because of the small size of poplar seeds (table 4), this is an unmanageable number of seeds for most species.

Nursery practice. Poplar, aspen, and cottonwood seedlings can be produced in containers or as bareroot stock. High-quality seedlings can be grown under either system or a combination of the two (for example, plug+1 stock). The choice of a seedling production system will be determined by climate, economics, the method/system of planting, available facilities and equipment, and the type of seedling (diameter and root system characteristics) that will best meet management objectives. Containerized production seems to be more common, particularly in northern areas where greenhouse production can provide a longer and warmer growing season.

Early nursery techniques for direct-sowing cottonwood seeds into seedbeds have been described by Bull and Muntz (1943), Einspahr (1959), Engstrom (1948), Gammage and Maisenhelder (1962), Maisenhelder (1951), Peterson and Peterson (1992), Schreiner (1974), and Wycoff (1960). Currently, both bareroot and container-grown aspen and aspen hybrid seedlings are being produced on a commercial scale. Bareroot seedlings are grown by direct-sowing cleaned seedlots onto seedbeds that are formed with sideboards and watered prior to sowing. Seeds are sown at a

density of 265 viable seeds/m² (25/ft²) to produce 42 to 63 plantable seedlings/m² (4 to 6/ft²) at lifting. The beds are lightly watering again after sowing, then covered with 1.3-cm ($^1/_2$-in) mesh hardware cloth and 50% shadecloth (Wyckoff 1996). Sowing is often done by hand: enough seeds to cover a given area of bed space are weighed out and sprinkled from vials with small holes drilled in the caps. Mechanical sowing is used where seeders capable of handling such small seeds are available.

Seedbeds are watered from an overhead irrigation system as needed during the first 3 weeks to maintain a moist surface without runoff or standing water; the seedbed covers are left in place during irrigation. The shadecloth is removed at 3 weeks, having served primarily to reduce surface drying and allowing irrigation without removal of seedbed covers. The hardware cloth is left in place until seedlings begin to reach it, for it can serve as protection against hail. Seedlings are lifted in the fall after leaf drop, then graded and placed in polyethylene lined boxes for storage at –2 to –4 °C. Packing material such as sphagnum moss, shredded wet newsprint, and hydromulch have been used to keep roots from desiccating during storage. The same technique has also been used successfully with cottonwood, balsam poplar, and poplar hybrids (Wyckoff 1996).

Containers of different sizes and shapes have been used to produce aspen seedlings. However, plug-type containers with cavity volumes of 350 to 450 cm³ (21 to 27 in³) provide sufficient growing space to produce a large seedling with 5 to 7 mm (0.2 to 0.3 in) root collar diameters and 60 cm (2 ft) heights in 1 growing season (Burr 1985; Wyckoff and others 1995). The containers are typically sown by hand or with precision mechanical seeders, germinated in a greenhouse, then moved outside for the remainder of the growing season. Seedlings are planted in the same year that they are grown or stored for planting the following year. The time of planting will determine the sowing schedule, provided greenhouses can be heated (Carlson and Fung 1996).

A third technique, using both greenhouse and nursery beds to produce plug+1 bareroot aspen seedlings, combines the advantage of seed-use efficiency of greenhouse containers with the production of a high number of large-diameter seedlings from seedbeds (Wyckoff 1996). Typically, seeds are mechanically sown into horticulture bedding flats with cavity volumes of 15 to 25 cm³ (0.9 to 1.5 in³) and 1,280 cavities/m² (119/ft²). These are kept under greenhouse conditions for 8 to 9 weeks. At the end of this time, 8- to 10-cm (3- to 4-inch) tall seedlings are transplanted into seedbeds at densities of 43 to 54 seedlings/m² (4 to 5 seedlings/ft²) and grown for one season. On average, it requires 1.5 to 2 viable seeds to produce 1 container seedling with a minimum 5-mm (0.2-in) root collar diameter; 5 to 6 viable seeds to produce a bareroot seedling with a minimum 7-mm (0.3-in) root collar diameter; and 2.7 seeds to produce a plug+1 bareroot seedling with a minimum 7-mm (0.3-in) root collar diameter. Seedlings grown in the plug +1 regime attain heights of 1 m (3.2 ft) in a single growing season (Wyckoff 1996).

The following features are common to all growing systems:

- Sowing is most efficient when seeds are separated from the hair, which makes it easier to control seeding density and distribution in nursery beds and containers.
- It is necessary to determine seedlot viability prior to sowing; this is particularly important for seeds that have been stored for several or more years.
- Covering seeds with more than a few millimeters of soil may significantly reduce germination (Maisenhelder 1951; McDonough 1979; Richter 1936).
- Maintaining adequate water content of the seedbed surface is critical for germination and establishment. Application of a fine spray of water causes less flooding of the seedbed and less seed movement, resulting in more rapid seedling establishment and more efficient use of seeds.
- Shading may be beneficial during germination, but seedlings will grow most rapidly in full light (Burns and Honkala 1990).
- Use of a fungicide may be necessary because of the continuous high moisture levels during early development (Shea and Kuntz 1956). This may be more critical in greenhouse production where temperature and relative humidity are more conducive to development of damping-off fungi.

Seedling production is important in breeding and clone development, but once desirable clones have been identified for use in intensively managed biomass and energy plantations they are propagated exclusively by vegetative reproduction. For a discussion of various aspects of vegetative reproduction see Dickmann and Stuart (1983), FAO (1980), Stettler and others (1996), and Dickmann and others (2001).

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Fabaceae—Pea family

Prosopis L.

mesquite

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Growth habit, occurrence, and use. Mesquites—the genus *Prosopis*—are deciduous, thorny shrubs or small trees native to the tropical or subtropical regions of the Western Hemisphere, Africa, the Middle East, and India (Sargent 1965). Three native and 1 naturalized species are considered here (table 1); all are small trees, rarely exceeding heights of 15 m. Mesquite wood is an excellent source of fuel and charcoal and enjoys heavy local use for fenceposts, crossties, and furniture. Mesquite legumes make high-quality forage for livestock and wildlife, and the seeds were widely used by native American peoples in the Southwest (Davis and others 1975; Martin and Alexander 1974; Vines 1960). The crude protein contents of honey and velvet mesquite seeds are 31 and 24%, respectively (Becker and Grosjean 1980), and the legumes of honey mesquite are high in carbohydrates (Harden and Zolfaghari 1988). Mesquite flowers are a source of excellent honey, especially in Hawaii (Skolmen 1990). The tree is a hardy nitrogen-fixer and has been planted for erosion control in Hawaii, as well as for highway landscaping and mine spoil reclamation in the Southwest (Day and Ludeke 1980).

Flowering and fruiting. Mesquite's tiny, perfect flowers are greenish white or greenish yellow in color. They are 2 to 3 mm in diameter and are borne in spike-like axillary racemes some 3 to 10 cm long. Flowering of the mesquites occurs generally from late March to September in the Southwest (Sargent 1965; Vines 1960). In Hawaii, mesquite begins to flower at ages of 3 to 4, and although flowering can occur throughout the year, it is most frequent in January to March (Skolmen 1990). The fruit is an indehiscent legume (pod) that ripens from August to September (figure 1) (Martin and Alexander 1974). Ripe legumes are typically yellowish in color, although legumes of velvet mesquite may also be a mottled red and black at maturity (Ffolliott and Thames 1983). Legumes of mesquite, honey mesquite, and velvet mesquite are flat in shape and vary from 10 to 30 cm in length. Those of screwbean mesquite are coiled and may be as long as 70 cm. The flat, tan or brown seeds range from 1.5 to 7 mm in length (Ffolliott and Thames 1983; Sargent 1965) (figure 2).

Figure 1—*Prosopis juliflora*, mesquite: legume.

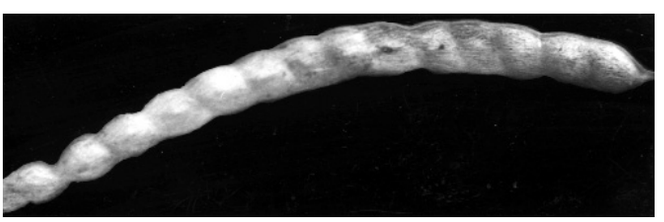
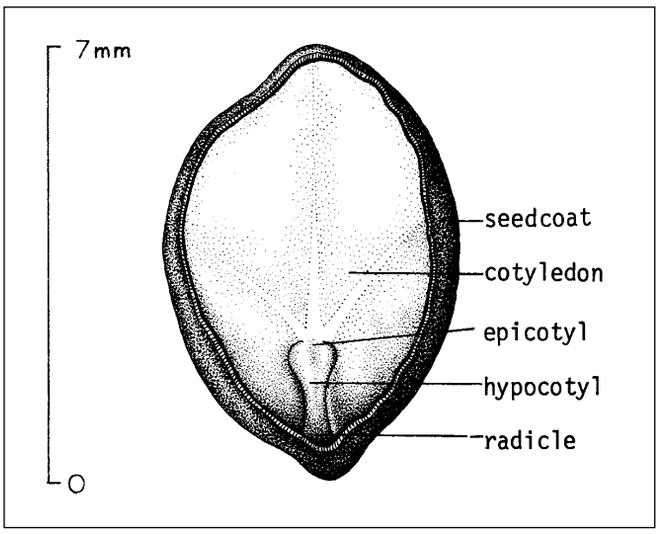


Table 1—*Prosopis*, mesquite: nomenclature and occurrence

Scientific name & synonym(s)	Common name(s)	Occurrence
***P. glandulosa* Torr.** *P. chilensis* var. *glandulosa* (Torr.) Standl. *P. juliflora* var. *glandulosa* (Torr.) Cockerell	**honey mesquite**	E Texas & Oklahoma to Utah, S California, & N Mexico
***P. juliflora* (Sw.) DC.**	**mesquite,** *kiawe* (Hawaii)	Mexico, S to Brazil & Peru
***P. pubescens* Benth.**	**screwbean mesquite,** screwbean, *tornillo*	Trans-Pecos Texas to Utah & S California
***P. velutina* Woot.** *P. juliflora* var. *velutina* (Woot.) Sarg.	**velvet mesquite,** mesquite	SW New Mexico, central Arizona, NW Mexico

Figure 2—*Prosopis juliflora*, mesquite: longitudinal section through a seed (**left**) and seeds (**right**).



Good seed production data are lacking, but there is a record from southern California of an average of 7.2 kg (16 lb) of fruits per tree from velvet mesquite (Felker and others 1984). In the same record, other yield averages were 2.2 kg/tree (5 lb) for honey mesquite, and less than 1 kg/tree (2 $^{1}/_{4}$ lb) for screwbean mesquite. There are numerous species of insects that feed on seeds of the mesquites; seed beetles (Bruchidae) are the most important group (Johnson 1983; Solbrig and Cantino 1975).

Collection, extraction, and storage. Ripe legumes may be stripped from trees by hand or picked up from the ground. Seed extraction and cleaning are not easy. One suggested method is to dry the legumes thoroughly (which may require oven-drying in humid climates) then running them through mechanical scarifiers or hammermills, and then screening out or blowing away the trash (Brown and Belcher 1979; Martin and Alexander 1974). Another method is to soak the legumes to soften them, then force the pulpy legumes and seeds through a sausage grinder with holes large enough for the seeds to pass. Hand grinders will suffice for small lots and commercial meat grinders have been successful for large lots (Skolmen 1990). Filled seeds may be separated from insect-damaged or immature seeds with aspirators or other blowers. If the seeds are dry, water flotation can also be used to separate good from damaged seeds. There are few seed yield and weight data for these 4 mesquite species: 1 kg of mesquite legumes may yield from 19,900 to 35,300 seeds (1 pound yields 9,025 to 16,000 seeds) (Goor and Barney 1968). Mesquite and honey mesquite average 8,000 to 30,000 seeds/kg (3,625 to 13,600/lb) (Glendening and Paulsen 1955; Von Carlowitz 1986), while as many as 38,300/kg (17,400/lb) have been reported for mesquite (Martin and Alexander 1974). Detailed studies of seed longevity are not available, but mesquite seeds, like those of most leguminous species, are orthodox in storage behavior. This means that seeds with low moisture contents may be stored at low temperatures for long periods without loss of viability. Air-dried seeds can be stored at ambient room temperature for at least 9 months with little loss in viability (Skolmen 1990). Martin (1948) reported that herbarium samples of velvet mesquite germinated after 44 years. Furthermore, mesquite seeds have been stored in liquid nitrogen (–196 °C) for 30 days without loss of viability (González-Benito and others 1994).

Pregermination treatments. Like most Fabaceae, mesquites have very hard seedcoats (that is, hardseededness) that require scarification as a pretreatment for timely germination. Small samples, such as those used in germination tests, can be scarified effectively by nicking each seed with a knife (Martin and Alexander 1974) or rubbing it on rough sandpaper, or by treating a small seedlot with a mechanical scarifier. For seedlots of any size, water soaks are often effective. For mesquite and honey mesquite, 48 hours in cold or tepid water or 1 hour in boiling water has been recommended (Von Carlowitz 1986). Seedcoat hardness may vary by year or seed source, however, and acid scarification may be required on some seedlots. For mesquite, 10 minutes in sulfuric acid increased the germination of a seedlot from 64 to 88% (Skolmen 1990). The safest procedure to use with hot water or acid treatments is to treat a few small samples to determine the best treatment period.

Germination. Some increases in germination capacity of mesquite seeds that resulted from scarification are shown in table 2. Germination of scarified seeds was complete 10 days after exposure to the test conditions. When velvet

Table 2—*Prosopis*, mesquite: germination test conditions and results

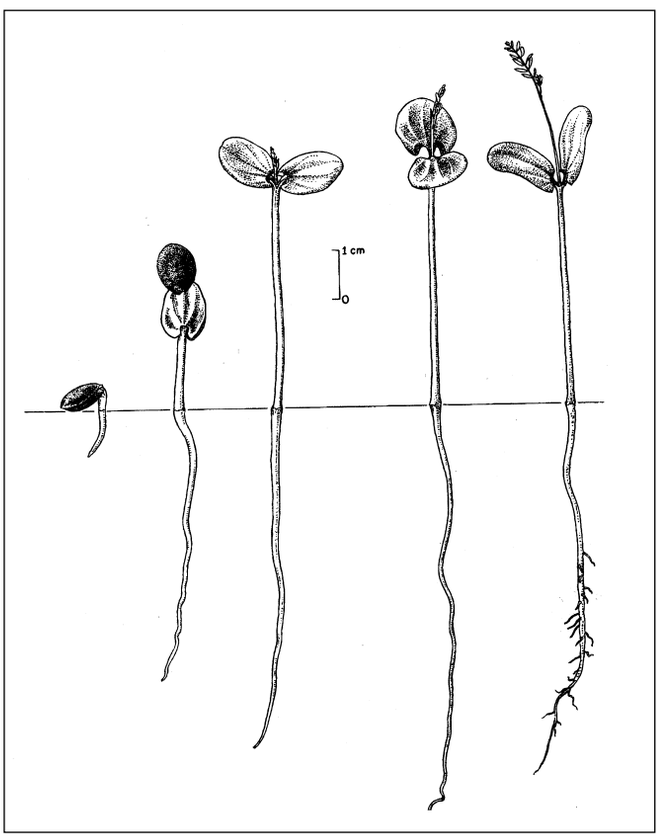
Seed age (yr)	Scarification treatment	Germination medium	Temp (°C) Day	Temp (°C) Night	Avg % germination
11	Nicking	Wet paper	27	27	98
50	Nicking	Wet paper	27	27	60
—	None	Wet paper	27	27	18
—	H_2SO_4	Wet sand	30	20	88

Source: Martin and Alexander (1974).

mesquite seeds were scarified with a knife, 94 to 100% of the seedlot germinated when kept at a constant 27 °C in the dark (Glendening and Paulsen 1955). Germination is epigeal (figure 3).

Nursery practices. There are few published guidelines for nursery practices, but growing mesquite seedlings should not be too difficult. Cox and others (1993) recommended a sowing depth of 1 to 2 cm ($^2/_5$ to $^4/_5$ in) for velvet mesquite. Greenwood cuttings from young plants of mesquite, honey mesquite, and velvet mesquite can be rooted in mist chambers (Felker and Clark 1981).

Figure 3—*Prosopis juliflora*, mesquite: seedling development at 1, 2, 5, 10, and 25 days after germination.



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Rosaceae—Rose family

Prunus L.

cherry, peach, and plum

Ted J. Grisez, Jill R. Barbour, and Robert P. Karrfalt

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Growth habit, occurrence, and use. The genus *Prunus*—often called the stone fruits—is one of the most important genera of woody plants. Its 5 well-marked subgenera include the plums and apricots *(Prunophora)*, the almonds and peaches *(Amygdalus)*, the umbellate cherries *(Cerasus)*, the deciduous racemose cherries (*Padus*), and the evergreen racemose or laurel cherries *(Laurocerasus)*. Plums can be distinguished from peaches and almonds by lack of a terminal bud, multiple flowers from a bud, and an elongated pedicel (Janick and Moore 1996). Plums can be distinguished from cherries by the lack of a terminal bud, the presence of a suture, a waxy bloom on the fruit, and a flatter pit.

Nearly 200 species—ranging from prostrate shrubs to trees over 30 m tall—are found in the Northern Temperate Zone, with a few in Central and South America (Harlow and Harrar 1958; LHBH 1978; Rehder 1940). By far the greatest number of species of cherries occur in eastern Asia (Hedrick 1915), but most of the long-cultivated food-producing species originated in Europe and western Asia (table 1). Over 100 species have been brought under cultivation, mostly as food crops or ornamentals (Rehder 1940), and 32 of the more important species for planting in the United States are described in table 1.

Many of the stone fruits have been cultivated since ancient times for their edible fruits and a few for edible seeds (almonds). Wild species have also been a source of food for Native Americans and early European settlers in this country and are still used to some extent. Many selections of wild plums have been propagated for fruit production. Several species are useful as ornamentals because of their showy flowers, variety of growth habits, relatively fast growth and ease of cultivation, and adaptability to a wide variety of soils and climates (Hedrick 1915; Olson and Nagle 1965; Rehder 1940; Strausbaugh and Core 1964).

Trees for fruit production and many ornamentals are propagated by budding or grafting, but seed production is necessary to grow the rootstocks and in breeding programs. The most important rootstock species and their scion combinations include almond rootstock for almonds and plums; apricot for apricots; mazzard cherry for sweet cherries; mahaleb cherry for sweet and sour cherries; peach for peaches, almonds, apricots, and plums; American plum for plums in cold climates; Bessey cherry for dwarf peaches; bullace plum (St. Julien types) for plums; myrobalan plum (mariana types) for almonds and plums; and myrobalan plum (myrobalan types) for plums (Cochran and others 1961; Sudworth 1908). Certain strains of peach, mahaleb cherry, and myrobalan plum are preferred for use as rootstocks because of their resistance to pests or for other qualities (Cochran and others 1961; Hedrick 1915).

Black cherry is the most important timber-producing species in the genus, but several others that attain sufficient size, such as mazzard cherry and mahaleb cherry in Europe and Japanese flowering cherry (*P. serrulata* Lindl.) in Japan, are used for wood products. Minor products include drugs, cordials, flavorings, honey, and perfume oil (Edlin 1967; Hedrick 1915). Probably all wild species are useful to wildlife as food. Birds and mammals eat the fruit, rodents eat the seeds, and deer (*Odocoileus* spp.) and beaver (*Castor canadensis*) use the leaves, twigs, and bark (Grisez 1974; Martin and others 1951; Van Dersal 1938). Several thicket-forming species of plums and cherries provide cover. Livestock feed on several species but others can be poisonous (Van Dersal 1938). Several species are used for erosion control and in shelterbelts (Engstrom and Stoeckeler 1941; Grisez 1974). In addition to those indicated in table 1, sour cherry, European bird cherry, and sloe are used for erosion control in Russia; and the same species plus mazzard cherry, apricot, myrobalan plum, garden plum, and pin cherry are used in shelterbelts (Al'benskii and Nikitin 1956; Koreisho and Morozov 1955).

Geographic races and cultivars. Very few racial differences affecting seed characteristics have been recognized.

Table 1—*Prunus,* cherry, peach, and plum: nomenclature, growth habit, and occurrence

Scientific name synonym(s)	Common name(s)	Growth habit	Occurrence
***P. alleghaniensis* Porter**	**Allegheny plum,** sloe, Allegheny sloe, Porter plum	Tree or shrub	Connecticut to Pennsylvania & S in mtns to Georgia; also in Michigan
***P. americana* Marsh.**	**American plum,** wild yellow plum, red plum, goose plum, hog plum	Tree or shrub	Massachusetts to Manitoba, New Mexico, central Texas & NW Florida
***P. angustifolia* Marsh.**	**Chickasaw plum,** sand plum	Tree or shrub	Missouri, S Nebraska to NW Texas & Louisiana; naturalized E to central Florida, New Jersey, & Illinois
***P. armeniaca* L.** *Armeniaca vulgaris* Lam.	**apricot**	Tree	W Asia; occasional escape from cultivation
***P. avium* (L.) L.** *P. cerasus avium* L. *Cerasus avium* Moench	**mazzard cherry,** sweet cherry, gean,* bird cherry*	Tree	Europe & W Asia; naturalized locally in SE Canada & E US
***P. caroliniana* (P. Mill.) Ait.**	**Carolina laurel cherry,** wild orange	Tree (evergreen)	North Carolina to Texas
***P. cerasifera* Ehrh.** *P. domestica* var. *myrobalan* L. *P. myrobalana* Loisel. *P. korolkowi* Vilm.	**myrobalan plum,*** cherry plum, marianna plum, flowering plum	Tree	W Asia; spread from cultivation from Washington to California, also in Michigan to Vermont, S to Ohio, New Jersey, & in Tennessee
***P. cerasus* L.** *Cerasus vulgaris* Mill.	**sour cherry,** pie cherry	Tree	W Asia & SE Europe; naturalized locally from Nova Scotia & Michigan to N Florida & W-ward
***P. domestica* L.** *P. damascena* Dierb. *P. communis* Huds.	**garden plum,** plum, European plum	Tree	W Asia & Europe; naturalized locally in SE Canada, NE US & Oregon
***P. domestica* var. *insititia* (L.) Fiori & Paoletti** *P. domestica insititia* Fiori & Paoletti	**bullace plum,** damson, damson plum	Tree or shrub	W Asia & Europe; naturalized locally from Nova Scotia & Maine to New York SW-ward
***P. dulcis* (P. Mill) D.A. Webber** *Prunus amygdalus* Batsch *Amygdalus dulcis* P. Mill. *P. communis* (L.) Arcang. *Amygdalus communis* L.	**almond**	Tree	W Asia & possibly North Africa; occasional escape from cultivation
***P. emarginata* (Dougl. ex Hook.) D. Dietr.** *P. mollis* Walpers *Cerasus prunifolia* Greene	**bitter cherry,** wild cherry, narrowleaf cherry	Shrub or tree	British Columbia to S California, Arizona, & Montana
***P. fasciculata* (Torr.) Gray**	**desert almond**	Shrub	California to Utah
***P. fremontii* S. Wats**	**desert apricot**	Shrub	S California
***P. gracilis* Engelm. & Gray**	**Oklahoma plum**	Shrub	Arkansas to Texas
***P. hortulana* Bailey**	**hortulan plum**	Tree	S Indiana to Iowa, Oklahoma, Arkansas, Alabama & W Tennessee
***P. ilicifolia* (Nutt. ex Hook & Arn.) D. Dietr.**	**hollyleaf cherry,** islay, evergreen cherry	Tree or shrub (evergreen)	Pacific Coast region, central to S California & in N Lower California, & Mexico

Differences in seed size, germination percentages, and other characteristics have been recognized, but these are likely to be treatment differences or simply random variations. For example, the moisture content of seeds (which is seldom reported) and tree-to-tree variation can have more effect than place of origin on numbers of seeds per weight (Grisez 1974). According to Hedrick (1915), "Cherries of any variety grown on poor soils or in uncongenial climates tend to have large stones and little flesh, while the pits are smaller and there is more flesh with the opposite extremes in environment." The weights of black cherry seeds increase with latitude (Pitcher 1984), ranging from 7 g in Florida to 14 g in northern Michigan. There is a significant negative correlation ($r = -0.35$) between seed size and germination in that smaller seeds have better germination (Pitcher 1984).

Table 1—*Prunus,* cherry, peach, and plum: nomenclature, growth habit, and occurrence (continued)

Scientific name synonym(s)	Common name(s)	Growth habit	Occurrence
***P. laurocerasus* L.**	**laurel cherry,** cherry-laurel	Tree (evergreen)	SE Europe, SW Asia
***P. mahaleb* L.** *Cerasus mahaleb* Mill.	**mahaleb cherry,** mahaleb, St. Lucie cherry, perfumed cherry	Tree	W Asia & Europe; naturalized locally in SW Canada & NE US
***P. maritima* Marsh.**	**beach plum**	Shrub	Maine to Delaware
***P. munsoniana* W. Wight & Hedrick**	**wildgoose plum,** Munson plum	Tree or shrub	Kansas, Kentucky, Texas & N Mississippi; naturalized E to S Ohio & Georgia
***P. padus* L.** *P. racemosa* Lam. *Padus racemosa* (Lam.) Schneid. *Cerasus padus* (L.) DC.	**European bird cherry,** mayday tree	Tree	Europe & N Asia to Korea & Japan; spread from cultivation in Canada & NE US
***P. pensylvanica* L. f.** *P. persicifolia* Desf. *P. montana* Marsh. *P. lanceolata* Willd.	**pin cherry,** fire cherry, wild red cherry, bird cherry	Tree or shrub	Newfoundland to British Columbia S to Colorado, South Dakota, Pennsylvania, & in mtns to Georgia
***P. persica* (L.) Batsch** *Amygdalus persica* L. *Persica vulgaris* Mill.	**peach,** common peach	Tree	China; naturalized locally, New England, S Ontario & Michigan to E Texas & Florida
***P. pumila* L.** *P. depressa* Pursh	**sand cherry**	Shrub	New Brunswick to Manitoba, Illinois, & New Jersey
***P. pumila* var. *besseyi* Bailey (Gleason)** *P. prunella* Daniels *P. pumila besseyi* (Bailey) Waugh. *P. susquehanae* Willd. *Cerasus canadensis* Mill.	**Bessey cherry,** western sand cherry, Rocky Mountain cherry	Shrub	Manitoba to Wyoming S to Kansas & Colorado
***P. serotina* Ehrh.** *P. virginiana* L. *Padus virginiana* (L.) Mill. *Padus serotina* Borkh.	**black cherry,** rum cherry, wild cherry wild black cherry,	Tree	Nova Scotia, S Ontario & Minnesota to E Nebraska, E Texas, & central Florida; also in Mexico & Guatemala
***P. spinosa* L.**	**sloe,** blackthorn	Shrub or tree	Europe, N Africa, & W Asia; naturalized locally in SE Canada & NE US
***P. subcordata* Benth.**	**Klamath plum,** Pacific plum, Sierra plum, western plum	Tree or shrub	W & S Oregon to central California
***P. tomentosa* Thunb.** *P. trichocarpa* Bge. *Cerasus tomentosa* Wall.	**Manchu cherry,** Nanking cherry downy cherry	Shrub	China, Japan, & Himalayas; central & N Great Plains
***P. umbellata* Ell.**	**hog plum**	Tree	North Carolina to Florida, Alabama, & Mississippi
***P. virginiana* L.** *P. nana* DuRoi *P. demissa* (Nutt.) D. Dietr. *Padus nana* (DuRoi) Borkh.	**common choke cherry**	Tree or shrub	Newfoundland to British Columbia, S to S California, New Mexico, Kansas, Illinois, Maryland, & S in mtns to Georgia

Sources: Grisez (1974), Wasson (2001).

* Names commonly used for the wild form.

There often are great differences among cultivars or groups within each of the domesticated fruit species, particularly in the percentage of viable seeds. In mazzard and sour cherries, the late-ripening cultivars, which require 80 days from flowering to fruit ripening, produce seedcrops with nearly 100% sound seeds. On the other hand, early cultivars, which require 60 days or less to ripen, produce almost no sound seeds. Those ripening in 60 to 75 days are intermediate (Tukey 1927). The final stage of fruit development is the rapid growth of the pericarp, and in early ripening cultivars of these species and peach, this stage begins before the embryo reaches full size (Tukey 1936). Garden plum also shows wide variation in germination capacity among cultivars tested under identical conditions (Suszka 1967). Immature embryos have been brought to a germinable stage by (1) growing excised embryos in artificial

culture, (2) storing whole fruit (Hesse and Kester 1955), and (3) not picking until the fruit is over-mature (Zielinski 1958). Current technology allows the successful culture of ovules as small as 0.6 mm (Janick and Moore 1996). Only 32% of embryos <10 mm long produce plants, compared to 78% for larger embryos (Ramming 1990).

Non-viability of apparently normal seeds derived from crossbreeding cherries or plums has been a problem (Cochran and others 1961). The Duke cherries—hybrids of mazzard cherry and sour cherry—often have empty seeds (Hedrick 1911).

Flowering and fruit-ripening dates vary among cultivars of a species grown in the same location (Hedrick 1911, 1915; Kester 1969). Individual trees of black cherry vary in a similar manner (Grisez 1974), and the same variation can be expected in other wild species. The food quality of fruit varies greatly among wild plants of Bessey cherry and the plums. Selections of 15 species of plums have been grown under cultivation for their fruit (Hedrick 1911, 1915).

American plum seeds from northern Minnesota germinate much better at a temperature of 10 °C than at higher temperatures, whereas those from Nebraska germinated as well and more rapidly at 21 °C (night) to 27 °C (day) (Grisez 1974).

In apricots, the variety called Russian apricot is hardier than the typical form (Grisez 1974). Mazzard cherry cultivars require 5 to 6 days longer to begin germination in stratification than wild mazzard cherry (Suszka 1967).

In a provenance study of black cherry, Cech and Kitzmiller (1968) found that the pattern of variation for seed traits is random throughout most of its range. However, seeds from the southern and southwestern parts of the range in the United States were characteristically lighter in weight and smaller in diameter as well as having thinner endocarps than seeds from other areas. Geographic locations and mother trees contributed about equally to the variability in total germination.

Flowering and fruiting. The flowers of nearly all species are bisexual. They normally have 5 white or pink petals and 15 to 20 or more stamens. In general, the pistil matures 3 or 4 days before the stamens (Hedrick 1915). The flowers are solitary, in umbel-like clusters or racemes, and usually appear before or with the leaves. The flowers are insect-pollinated. Except for plums and sweet cherries, most species are self-fertile and thus a tree will set fruit without a cross-pollinator (Janick and Moore 1996).

Of the 2 ovules, only 1 normally develops, resulting in a 1-seeded drupe. The drupe is thick and fleshy (except in the almonds) and has a hard, bony endocarp surrounding the seed itself (figures 1–3) (Fernald 1950; LHBH 1976; Kester 1969; Knuth 1906–09; Rehder 1940). The developed endocarp and seed are commonly called the stone or pit. Dates of flowering and fruiting are listed in table 2. Seeds are distributed mainly by birds and mammals (Grisez 1974). Fruit diameters of most species are between 5 and 25 mm, but

Figure 1—*Prunus*, cherry, peach, plum: seeds of *P. americana,* American plum (**upper left**), *P. angustifolia*, Chickasaw plum (**upper middle**); *P. armenica*, apricot (**upper right**); and *P. persica*, peach (**bottom**).

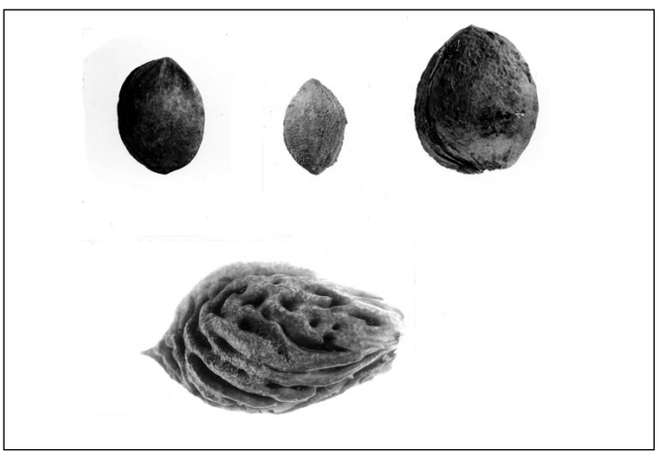


Figure 2—*Prunus*, cherry, peach, plum: seeds of *P. avium*, mazzard cherry (**top left**); *P. padus*, European bird cherry (**top right**); *P. pumila* var. *besseyi*, Bessey cherry (**second row left**); *P. pensylvanica*, pin cherry (**second row right**); *P. cerasus*, sour cherry (**third row left**); *P. pumila*, sand cherry (**third row right**); *P. marginata*, bitter cherry (**fourth row left**); *P. serotina*, black cherry (**fourth row right**); *P. mahaleb*, mahaleb cherry (**fifth row left**); *P. virginiana*, common choke cherry (**fifth row right**); *P. subcordata*, Klamath plum (**bottom left**); and *P. umbellata*, hog plum (**bottom right**).

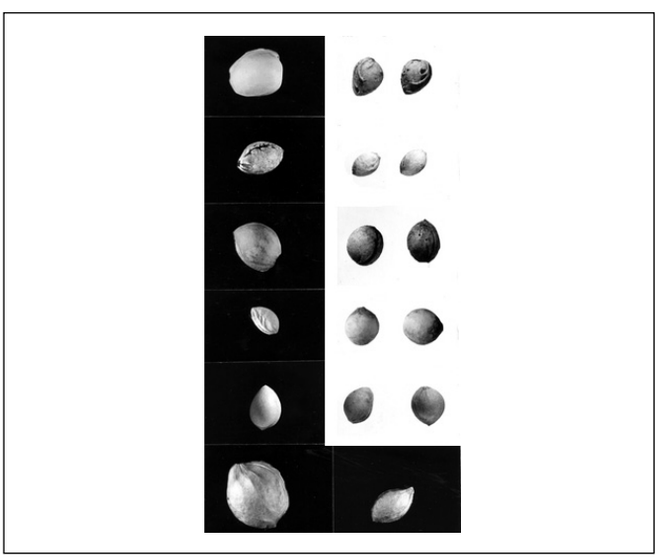


Table 2—*Prunus*, cherry, peach, and plum: phenology of flowering and fruiting

Species	Location	Flowering	Fruit ripening	Seed dispersal
P. alleghaniensis	Scattered	Late Apr–May	Aug–Sept	—
P. americana	—	Mar–May	June–Oct.	June–Oct
P. angustifolia	—	Mar–Apr	May–July	May–July
P. armeniaca	California	Feb–Mar	May–June	—
	USSR	Mar–Apr	July	July–Aug*
P. avium	NE US	Apr–May	June–July	—
P. caroliniana	SE US	Mar–Apr	Sept–Oct	—
P. cerasifera	Geneva, New York	May 12†	July 15–Aug 10	—
	USSR	Apr–May	Aug	—
P. cerasus	—	Apr–May	June–July	—
	Geneva, New York	May 8–18†	June–July	—
P. domestica	Geneva, New York	May 12–21†	July 15–Oct 1	—
	USSR	May	Aug	—
P. d. var. *insititia*	US & Canada	Late Apr–May	Aug–Sept	—
	Geneva, New York	May 16–21†	Aug 20–Oct 1	—
P. dulcis	California	Mid Feb–Mar	Late Aug–Oct*	—
P. emarginata	—	Apr–June	July–Sept	Aug–Sept*
P. hortulana	SE US	Mar–May	Aug–Oct	—
P. ilicifolia	—	Mar–May	Sept–Oct*	Oct–Dec
P. laurocerasus	SE Europe & Asia Minor	Apr–May	July–Aug	—
P. mahaleb	NE US & SE Canada	Apr–May	July	—
P. maritima	Maine to Delaware	Apr–June	Sept–Oct	—
P. munsoniana	—	Mar–May	July–Sept*	—
	Geneva, New York	May 20–24†	July 15–Sept 10	—
P. padus	Philadelphia & vicinity	End Apr–early May	Late June–July	—
	USSR	May–early June	June–Aug	Aug*
P. pensylvanica	—	Late Mar–early July	July–Sept	—
	Warren Co., Pennsylvania	May 1–15	Late July–early Aug	—
P. persica	NE US	Apr–May	July–Sept	—
	SE US	Feb–Apr	May–Aug	—
P. pumila	—	May–July	July–Sept	—
P. pumila. var. *besseyi*	Nebraska	Apr–May	July–Sept	July–Sept
P. serotina	Central Mississippi	Early Apr	June–July	July
	N Pennsylvania	Late May–early June	Late Aug–Sept	Aug 20–Sept; rarely Nov
	—	Late Apr–June 10	June–Sept.	July 1–Sept
P. spinosa	USSR	Apr–May	Aug–Sept	Sept
P. subcordata	—	Mar–May	Aug–Sept	—
P. tomentosa	Cheyenne, Wyoming	Early May	Late July	Early Aug
	Bismarck, N Dakota	May 10–15	July 10–15	July 15–Sept 1
P. umbellata	SE United States	Mar–Apr	Aug–Sept	—
P. virginiana	E US	Late Apr–early June	July–Oct	—
	Warren Co., Pennsylvania	May 10–20	Early Aug	—
	California	—	Aug–Sept*	—

Sources: Altman and Dittmer (1962), Bailey (1976), Bonner (1975), Fernald (1950), Grisez (1974), Hedrick (1911), Hedrick (1915), Hitchcock and others (1961), Kester (1969), Koreisho and Morozov (1955), Long (1923), McMinn (1959), Mirov and Kraebel (1937, 1939), Munz and Keck (1959), Pane (1966), Petrides (1958), Radford and others (1964), Rehder (1940), Sudworth (1908), Van Dersal (1938).

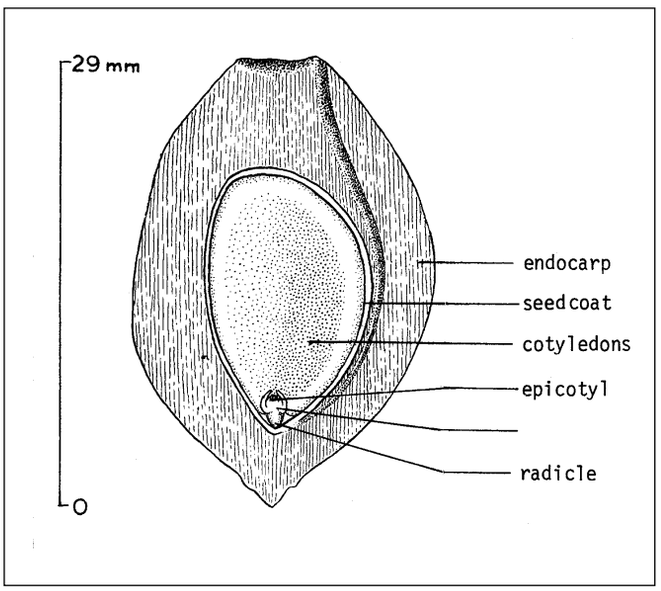
* Collecting dates.

† Average dates of height of bloom for one to several cultivars.

those of almonds, apricots, plums, and peaches are larger (table 3).

Collection of fruits. *Prunus* fruits should be collected when fully mature (Al'benskii and Nikitin 1956; Swingle 1925; Zielinski 1958); doing so facilitates cleaning and is more likely to result in good germination (Grisez 1974; Huntzinger 1968). It is especially important in certain cultivars when the seeds are in a critical stage at the time the fruits are ripe and may not develop to a sound condition if the fruits are picked prematurely (Tukey 1927). Height, seed-bearing age, seedcrop frequency, and fruit descriptions of 24 species are listed in table 3. Color and condition of the fruits indicate maturity. For those species in which the ripe fruit color is nearly black, the preripe color is red. In red-fruited species, the preripe color may be yellowish or partly green and red (Grisez 1974). Almonds are ready to harvest when the husks (mesocarps) of fruits in the inner parts of the tree crown have split (Kester 1969).

Figure 3—*Prunus persica*, peach: longitudinal section through a seed showing no endosperm. Seven species of *Prunus* have seeds without endosperm and 20 species have seeds with endosperm.



Fruits are collected by hand-stripping or by spreading sheets of suitable material under trees to catch the natural fall or fruits that are shaken or beaten off the tree (Grisez 1974; Huntzinger 1968; Stoeckeler and Jones 1957). Small quantities can be picked from the ground (Huntzinger 1971). Black cherry fruits may be collected from trees felled in logging, but when fruits have reached the dead-ripe stage, a high proportion of them will be knocked off during felling (Huntzinger 1968). Mechanical tree shakers are used in many commercial fruit orchards (Kester 1969; Miller 1960). There is even a machine to pick prunes (certain cultivars of garden plum) from the ground (Miller 1960).

Fruits may be carried in bags in small quantities—or in large quantities if they are to be processed immediately (Huntzinger 1971)—but boxes or baskets provide better protection against bruising and spoilage (Al'benskii and Nikitin 1956). Commercial cherries are often transported in water (Tennes and others 1968). Although this method was designed to protect the fruit, it could also be used to prevent spoilage and fermentation until the seeds are cleaned.

Extraction of seeds. Although satisfactory results have been obtained in a few cases by handling and sowing whole fruits (Engstrom and Stoeckeler 1941; Huntzinger 1968), it is generally desirable to clean the seeds of all pulp and juice (Heit 1945; Huntzinger 1968; Marcet 1951; Nyholm 1951; Robertson 1948–49; Shumilina 1949). Cleaning is done by macerators or hammermills with water to float off or screen out the pulp (Defler 1937; Dorn and Flick 1969; Grisez 1974; Hartman and Kester 1959; Huntzinger 1968; Steavenson 1940; Stoeckeler and Jones 1957). Hammermills should have worn or rounded hammers and be run at low speed (Mugford 1969). Small quantities may be cleaned by soaking and rubbing the fruits over a screen (Haut 1938; Jones 1963; Paton 1936) or by use of a household food blender (Huntzinger 1968).

Fermentation has been used to soften fruit to facilitate cleaning (Engstrom and Stoeckeler 1941; Grisez 1974; Rudolf 1961), but it is risky because the germination capacity of seeds may be severely reduced if seeds are allowed to become too warm or ferment too long (Cochran and others 1961; Engstrom and Stoeckeler 1941; Fogle 1958; Heit 1967). Fruits that are badly infested with brown rot should be discarded because this disease can spread through the seedlot (Janick and Moore 1996).

There is little need to separate out sound seeds in most species because the percentage of sound seeds is usually 96 to 100%, but it may be desirable in certain cultivars of commercial fruits. Separation of sound seeds of sour cherry has been done with 95% ethyl alcohol, density 0.8114 (Tukey 1927). A 17% salt solution (density 1.176) has been used to separate the heavy seeds of mazzard cherry, mahaleb cherry, and pin cherry, but the method is not always reliable (Cummings and others 1933). Seeds that float in water can be removed in the cleaning process, but some seeds that sink are not viable (Swingle 1925; Tukey 1927). The same methods should not be used with dried seeds because included air spaces can cause good seeds to float.

Seed yields and weights are listed in table 4. Additional data include the following weights per volume of fruit: sour cherry nested in water, 77 kg/hl (60 lb/bu) (Tennes and others 1968); black cherry, 72 kg/hl (56 lb/bu) (Stoeckeler and Jones 1957); and Manchu cherry, 77 to 85 kg/hl (60 to 66 lb/bu) (Grisez 1974). A bushel of black cherry fruit yields 5 kg (11 lb) of seed (Stoeckeler and Jones 1957).

Storage. Early experiences suggested that excessive drying for storage was detrimental (Cochran and others 1961; Engstrom and Stoeckeler 1941; Fogle 1958; Grisez 1974; Huntzinger 1968; Olson and Nagle 1965; Stoeckeler and Jones 1957); however, what was excessive was not defined. Very early ripening female parents may not produce fruits with fully mature embryos and these fruits should not be allowed to dessicate (Janick and Moore 1996). Apricot seeds can be dried to 6% moisture, mazzard cherry to 9 to 11%, and mahaleb cherry to 8% for storage without impair-

Table 3—*Prunus,* cherry, peach, and plum: height, seed-bearing age, seedcrop frequency, fruit color, and fruit size

Species	Height at maturity (m)	Year first cultivated	Min seed-bearing age (yrs)	Years between large crops	Ripe fruit color	Fruit size (mm)	
						Diameter	Length
P. alleghaniensis	4.9	1889	4	1	Dark purple	10	—
P. americana	3–9	1768	4	1–2	Red or yellowish	20–30	—
P. angustifolia	4.3–7.6	~ 1874	2	—	Red or yellow	10–20	—
P. armeniaca	10.4	Early	5	2	Yellowish with red	30+	—
P. avium	9–30.5	Early	6–7*	1	Yellow to red or purplish black	20–25	—
P. caroliniana	5.5–12	—	—	—	Black	10–13	10–13
P. cerasifera	8.2	Early	3	2–3	Red	16–25	—
P. cerasus	9–15	Early	6-7*	1	Light to dark red	8–25	—
P. domestica	9–12	Early	5	—	Often blue-purple	30+	—
P. d. var. *insititia*	6–7.6	Early	—	—	Yellow to bluish black	25+	15–20
P. dulcis	3–9	Early	4†,6–7	1	Brownish	30+	30–60
P. emarginata	1–15	1918	—	—	Bright red	8–12	—
P. fasciculata	1–2.4	—	—	—	—	13	
P. fremontii	1.5–3.7	—	—	—	Yellowish	15–20	13
P. gracilis	4.6	—	—	—	Red	13	—
P. hortulana	9	—	3	—	Red to yellow	25	—
P. ilicifolia	7.6–9	Pre-1925	3	—	Purple or black	13–17	25
P. laurocerasus	5.5	—	—	—	Purple to black	10	8–13
P. mahaleb	6–10	Early	3	1–2	Black	8–10	6–10
P. maritima	3	—	3	—	Purple	13–25	20
P. munsoniana	6–9	Pre-1909	3	—	Red or yellow	20–30	15–25
P. padus	15	Early	—	2	Black in typical variety	6–8	—
P. pensylvanica	3–12	1773	2	—	Light red	5–7	—
P. persica	3–7.6	Early	3	1–2	Yellow to red	30–60	30–75
P. pumila	0.3–2.4	1756	—	—	Purple-black	10	10
*P.*var. *besseyi*	0.3–1.2	1892	2–3	—	Purple to black	15	—
P. serotina	15.3–33.5	1629	5	1–5	Black	7–10	6–10
P. spinosa	4	Early	—	1–2	Blue-black	10–15	15
P. subcordata	3–7.6	~ 1850	—	2	Red or yellow	20–30	15–30
P. tomentosa	1.8–3	1870	2–3	1–2	Red	10–31	15
P. umbellata	—	—	3	—	Black, red, yellow	10–15	10–13
P. virginiana	1.8–9	1724	—	—	Red-purple to dark purple	8	—

Sources: Bailey (1976), Everett (1957), Fernald (1950), Giersbach and Crocker (1932), Grisez (1974), Gysel and Lemien (1964), Hedrick (1911, 1915), Huntzinger (1971), Kester (1969), Koreisho and Morozov (1955), Munz and Keck (1959), Peck (1961), Petrides (1958), Rehder (1940), Strausbaugh and Core (1964), Van Dersal (1938).

* Minimum commercial seed-bearing age.

† Ages are for seedling stock; grafted or budded stocks bear seeds 1 or 2 years younger (Wright 1966).

ing their germination (Suszka 1964). Seeds to be sown or stratified immediately need not be dried at all. Seeds to be used within a few weeks or months should only be surface-dried; apparently, excessive drying of seeds to be used within a year of collection is often harmful (Grisez 1974; Huntzinger 1968). For storage of 1 year or more, it is desirable to reduce the moisture content of seeds below the surface-dry condition. For mazzard cherry, the optimum moisture content is 9 to 11%, with optimum temperatures of –1 to 3 °C for storage up to 3 years and –10 °C for longer storage (Suszka and others 1996). The results of several storage studies are reported in table 5. In most cases, drying is done at room temperatures or lower. Surface drying usually requires only a few hours (Huntzinger 1968). The moisture content of black cherry seeds has been reduced from about 14% to 5% by drying at 32 °C for 3 hours (Huntzinger 1971).

Sealed containers are preferred for Prunus seeds if the moisture content is to be closely controlled. Seeds of mazzard cherry were dried to a moisture content of 11% and stored in sealed bottles at 1 °C for 4 $^{1}/_{2}$ years. During this period, viability decreased from 93% to 84% (Suszka 1970). Plastic bags have been satisfactory for storage of black cherry seeds for at least 3 years at cold temperatures (Huntzinger 1971). Cloth sacks may serve for short periods in cool temperatures (Suszka 1967). Maheleb cherry and

Table 4—*Prunus*, cherry, peach, and plum: seed data

Species	Seed weight/45 kg (100 lb) of fruit: Range kg	Range lb	Average kg	Average lb	Cleaned seeds/weight: Range /kg	Range /lb	Average /kg	Average /lb	Samples
P. alleghaniensis	—	—	—	—	—	—	2,950	338	1
P. americana	3–15	7–34	9	19	550–1,500	250–680	870	395	27+
P. angustifolia	4–14	8–30	7	16	770–1,530	350–694	1,030	467	14+
P. armeniaca									
USA	14–18	30–40	—	—	200–560	91–254	317	144	10+
USSR	5–7	10–15	—	—	270–495	123–225	382	173	—
P. avium									
USA	3–11	7–25	3	12	1,450–3,000	658–1,361	2,360	1,070	9+
USSR	7–8	15–18	—	—	1,640–2,770	3,616–6,108	4,740	2,150	—
P. cerasifera	—	5	10		782–1,330	355–603	994	451	7+
P. cerasus	—	—	9	20	1,510–4,000	685–1,815	2,910	1,320	6+
P. domestica	—	—	5	10	416–907	189–411	597	271	5+
P. d. var. *insititia*	—	—	3	7	625–1,920	284–871	1,380	626	3+
P. dulcis	—	—	—	—	126–225	57–102	181	82	3+
P. emarginata	—	—	11	25	4,120–8,790	1,869–3,987	7,020	3,184	6+
P. ilicifolia	—	—	—	—	200–240	91–109	220	100	2+
P. mahaleb	9–11	20–25	—	—	4,800–5,600	2,177–2,540	5,200	2,359	—
P. munsoniana	—	—	—	—	900–2,240	408–1,016	1,690	767	3+
P. padus	—	—	9	20	6,600–12,300	2,994–5,580	8,910	4,042	5+
P. pensylvanica	7–12	16–27	—	—	8,000–21,800	3,629–9,889	14,200	6,442	6+
P. persica	—	—	9	20	72–244	33–111	156	71	6+
P. pumila									
typical	—	—	—	—	2,460–4,000	1,116–1,815	2,920	1,325	4+
var. *besseyi*	7–13	15–28	10	21	1,500–4,000	681–1,815	2,400	1,090	10+
P. serotina									
fresh seeds	—	—	9	20	2,800–6,040	1,270–2,740	4,240	1,923	68
fresh & stored seeds	6–15	14–33	10	21	2,840–13,800	1,288–6,260	5,370	2,436	197
P. spinosa	—	—	5	10	1,970–2,670	894–1,211	2,240	1,016	—
P. subcordata	—	—	—	—	450–631	204–286	556	252	4+
P. tomentosa	3–5	7–12	5	10	1,730–6,400	785–2,903	4,740	2,150	9+
P. virginiana	8–11	18–25	9	20	3,010–8,400	1,315–3,810	4,790	2,173	19

Sources: Benjdl (1954), Cech and Kitzmiller (1968), Chittenden (1927), Cumming and others (1933), Defler (1937), Engstrom and Stoeckeler (1941), Everett (1957), Glazebrook (1941), Grisez (1974), Huntzinger (1971), King (1947), Koreisho and Morozov (1955), Krefting and Roe (1949), Krier (1948), Mirov and Kraebel (1937, 1939), Swingle (1939), USDA (1961), Van Dersal (1938).

myrobalan plum can be stored up to 2 winters at room temperature in jute sacks without loss of viability (Grzeskowiak and others 1983). Pin cherry seeds retained high viability after 10 years of storage at 1 to 3 °C under sealed conditions (Dirr and Heuser 1987).

Normally, storage temperatures should be within the range 0.6 to 5 °C, although American plum, mazzard cherry, and mahaleb cherry have been successfully stored at room temperatures for 2 to 5 years. American plum seeds can be stored at room temperature up to 30 months without loss of germinative capacity (Giersbach and Crocker 1932). Manchu cherry seeds stored for 21 months at room temperature did not lose viability (Dirr and Heuser 1987). Dried seeds of mazzard and mahaleb cherries and myrobalan plum can be stored up to 3 winters at –1 or –3 °C without significant loss of viability (Grzeskowiak and others 1983). Over 80% germination was obtained on black cherry seedlots containing 5% moisture after storage for 3 years in a freezer, but seedlots with about 15% moisture were completely spoiled when frozen (Huntzinger 1971).

Warm storage at a high moisture content for only a few months is harmful to seeds of mazzard cherry (Coe and Gerber 1934; Suszka 1967), black cherry (Huntzinger 1968), common choke cherry (Engstrom and Stoeckeler 1941), and probably other species as well. Black cherry seedlots should not be stored warm and moist more than 4 or 5 weeks, although about 2 weeks of such storage immediately after cleaning may be helpful for seeds about to be stratified (Huntzinger 1971).

Tables 5—*Prunus,* cherry, peach, and plum: germination of seeds after dry storage*

Species & storage period	Storage temp (°C)	Moisture content (%)	Germination (%)
P. americana			
18 months	7–10	Dry	70
53 months	7–10	Dry	45
18 months	Lab temp	Dry	72
53 months	Lab temp	Dry	16
18 months	30+	Dry	62
53 months	30+	Dry	0
P. avium			
7 years	–5	~10?	91–97
15 years	–5	~10?	98
55 months	1	11	84
55 months	1	11	88†
8-12 months	3	9–11	98–100
207 days	–3	8.6	100*
214 days	–3	9.0	99†
570 days	–3	8.6	100†
571 days	–3	9.5	94†
935 days	–1	8.3	99†
213 days	–3	9.0	99†
214 days	–3	8.9	98†
568 days	–3	8.6	100†
P. pensylvanica			
2 months	–18	Dry	95
6 years	1–3	Low	74
10 years	1–3	Low	76
P. serotina			
1 year	–18 to –14	4–6	52
2 years	–18 to –14	4–6	81
3 years	–18 to –14	4–6	81
5 years	–18 to –14	4–6	47
8 years	–18 to –14	4–6	66
1 year	–18 to –14	11–13	4
2 years	–18 to –14	11–13	7
3 years	–18 to –14	11–13	1
5 years	–18 to –14	11–13	4
8 years	–18 to –14	11–13	0
1 year	0.5–5	4–6	63
2 years	0.5–5	4–6	81
3 years	0.5–5	4–6	90
5 years	0.5–5	4–6	69
8 years	0.5–5	4–6	56
1 year	0.5–5	11–13	72
2 years	0.5–5	11–13	88
3 years	0.5–5	11–13	77
5 years	0.5–5	11–13	0
8 years	0.5–5	11–13	0

Sources: Ellis and Hong (1986), Giersbach and Crocker (1932), Grisez (1976), Heit (1967), Huntzinger (1971), Laidlaw (1983), Michalska and Suszka (1980c&d), Solovieva (1966, 1978), Suszka (1970).

† Viability determined by indigo carmine embryo-staining test (2 hours in 0.05% solution at 20 °C).

Pregermination treatments and germination tests. *Prunus* seeds have embryo dormancy and require a period of after-ripening in the presence of moisture and oxygen to overcome it. Because of their stony endocarps, *Prunus* seeds are often been thought to have seedcoat dormancy. The endocarp may offer some resistance to germination, but it is permeable to water and *Prunus* is not truly hard-seeded (Hartman and Kester 1959; Heit 1967; Tukey 1924).

Several mechanical and chemical methods have been used in attempts to crack, remove, or soften the endocarp, including freezing, mechanical scarification, boiling water, sulphuric acid, citric acid, lye, or hydrogen peroxide. In most cases, no advantage could be shown, and in many cases the treatments were detrimental. Peach seeds can be removed from the endocarp by applying pressure in the dorsal–ventral axis with a vise or special hand-clippers with a 2-sided blade (Janick and Moore 1996).

Removal of the endocarp by hand hastened or increased germination in American plum (Giersbach and Crocker 1932), almond (Gaudio and Pedone 1963), mazzard cherry (Zielinski 1958), sour cherry (Havis and Gilkeson 1949), peach (Crocker 1927, 1931), and sloe (Shumilina 1949). There was no advantage for bullace plum (Grisez 1974). Soaking for 48 hours in 0.1% citric acid resulted in 89% germination of black cherry; untreated seeds in this study germinated 57% (Jones 1963). In other studies, no advantage could be shown for citric acid treatments (Huntzinger 1968). Notching the endocarp and notching plus a hydrogen peroxide soak increased germination of an early-ripening mazzard cherry cultivar but had no effect on a late-ripening cultivar (Zielinski 1958). Gibberellin treatments apparently can substitute for a portion of the stratification period in apricot (Chao and Walker 1966), mazzard cherry (Fogle and McCrory 1960; Pillay 1962), garden plum (Janick and Moore 1996), and peach (Chao and Walker 1966), but it was effective only when the endocarp had been removed. Germination of mahaleb cherry seeds that were stored dry for several months was improved by 3 days of water-soaking prior to stratification (Swingle 1925).

Because good germination has been attained on stratified seeds of nearly all species of *Prunus* (table 6), it is evident that other pregermination treatments are not necessary if a seedlot is handled properly.

Although sand has often been used as a stratification medium, peat or sand–peat mixtures are preferred (Crocker 1930; Fogle and McCrory 1960; Huntzinger 1968; Shumilina 1949). Vermiculite was as good as peat in a test with black cherry seeds (Huntzinger 1971). Peat provides a larger and more constant supply of both air and water than sand (Crocker 1930; Shumilina 1949). The seeds are thoroughly mixed with the moist stratification medium. When peat is used, it should be soaked, then squeezed to remove all free water. The seeds should be mixed with about 1 to 3 times their volume of the medium (Crocker 1930; Grisez 1974; Huntzinger 1971). Seeds that had been dried for storage or those requiring a long period of after-ripening are sometimes stratified underground, in basements, or in shade prior to cold stratification or fall-sowing (Koreisho and Morozov 1955; Shumilina 1949).

Published results of experimental comparisons among various stratification temperatures for several species show that constant temperatures from 2 to 5 °C are more favorable than those below 1.7 °C or above 8 °C (Coe and Gerber 1934; Crocker 1931; Haut 1938). Seeley and Damavandy (1985) found that the optimum chilling temperature was between 4 and 6 °C for apricot, mazzard cherry, mahaleb cherry, and peach. The most suitable temperature for stratification of almond (cv. 'Truioto') with endocarp was 10 °C for 26 days (Therios 1982). A regularly alternating temperature range of 2 to 4 °C was better than constant 3 °C for 2 cultivars of mazzard cherry (Zielinski 1958).

Stratification periods necessary for after-ripening vary by species (table 6). In general, species and cultivars from warm climates require less chilling than those from cold climates. Satisfactory germination of the many cultivated species not included here can probably be attained by following general recommendations and the stratification requirements for closely related species of the same climatic zones.

Lockley (1980) stratified 13 open-pollinated families of common choke cherry for 10, 16, and 24 weeks at 3 °C and germinated the seeds at 3 alternating temperature regimes of 10 to 16 °C, 16 to 21 °C, and 21 to 27 °C. All germinating seeds were provided with 14 hours of light during the high-temperature portion of the cycle. Stratification for 10 weeks was inadequate. The best results, 77% germination on the average, were found with 16 weeks of stratification and germination at 21 to 27 °C. After 24 weeks of cold stratification, over 50% of the common choke cherry seeds germinated in stratification. There was a significant correlation ($r = 0.67$) between field emergence and laboratory germination at 16 to 21 °C and 21 to 27 °C when the seeds received 16 weeks of stratification. Common choke cherry families with low germination at 21 to 27 °C after 10 weeks of stratification were also low germinators in the nursery ($r = 0.68$).

In a comprehensive study on stones of 7 widely planted species of *Prunus* including several cultivars and seed sources, germination was much higher after warm plus cold stratification than after cold stratification only. The schedule was 14 days at 20 °C followed by 189 days at 3 °C (Suszka 1967). Seedlots of sloe given 2 weeks of warm stratification treatment followed by 18 weeks of chilling yielded 80% germination (Gordon and Rowe 1982). Myrobalan plum and garden plum germination was promoted by 2 weeks of warm stratification at 20 °C before chilling (Michalska and Suszka 1980b). Muller and others (1990) found that 3 cycles of warm and cold stratification at a moisture content of 30% improved the germination of mazzard cherry. Virtually full germination of Mazzard cherry seedlots was achieved with 2 weeks at 20 °C, 8 weeks at 3 °C, 2 weeks at 25 °C, then 3 °C for the remainder of the treatment (Michalska and Suszka 1980a).

Table 6—*Prunus*, cherry, peach, and plum: stratification periods, germination test conditions, and results

Species	Recommended stratification (days)		Germ. test conditions			Avg germination		Viability
			Temp (°C)					
	Warm*	Cold†	Day	Night	Days	(%)	Samples	(%)
P. alleghaniensis	0	150	10	10	60	25	7	—
P. americana	0	90–150	10	10	60	60	21	74
P. angustifolia	0	60–120	—	—	60	55	—	90
P. armeniaca								
endocarp removed	0	0	—	7	7	14	90	3
endocarp intact	14	189	3	3	‡	95	—	4
endocarp intact	0	80–90	5	5	‡	95	—	—
P. avium								
endocarp removed	0	90–125	21	21	—	91	—	69
endocarp intact	0	120–180	21	21	—	76	10+	—
endocarp intact	14	189	3	3	‡	88	—	—
P. caroliana	0	30–60	—	—	—	—	—	—
P. cerasifera	—	196	å1	å7	28	65	2	—
P. cerasus	0	90–150	—	—	—	—	82	—
P. domestica	14	189	3	3	‡	56	15	—
	0	120–150	—	—	—	—	85	—
	0	90	2	2	—	—	91	—
P. domestica var. *insititia*	0	84–112	18	18	—	89	7	—
P. dulcis	0	65	2	2	‡	—	90	—
P. emarginata	0	90–126	24	24	60	4	3+	—
P. ilicifolia								
fresh seed	0	0	—	—	—	—	—	—
stored seed	0	90	—	—	—	—	24	—
P. laurocerasus	0	60–90	—	—	—	—	—	—
P. mahaleb	0	80–100	—	—	—	89	5	—
	14	189	3	3	‡	55	3	—
P. maritima	0	90	—	—	—	—	39	—
P. munsoniana	0	80–100	—	—	—	100	10	—
P. padus								
fresh seeds	0	100–120	—	—	—	85	—	—
stored seeds	14	210	3	3	‡	50	3	—
P. pensylvanica	60	90	25	10	60	62	2	91
P. persica								
endocarp intact	0	98–105	5(§41)	5(§41)	‡	32	8	—
endocarp removed	0	70–105	5(§41)	5(§41)	‡	82	8	92
P. pumila var. *besseyi*	0	120	—	—	—	60	72	—
P. serotina	0	120	26	10	40–60	86	32	80
	14	189	3	3	‡	90	3	—
P. spinosa	0	170	—	—	—	—	90	—
P. subcordata	0	90	—	—	100	1	—	—
P. tomentosa	0	60–90	—	—	—	11	—	86
P. virginiana	0	120–160	25	10	40	77	3	62

Sources: Afanasiev (1940, 1942), Al'benshkii and Nikitin (1956), Chadwick (1935), Chao and Walker (1966), Coe and Gerber (934) Crocker (1927, 1931), Defler (1937), Dirr and Heuser (1987), Emery (1964), Engstrom and Stoeckeler (1941), Everett (1957), Fogle (1958), Fogle and McCrory (1960), Glazebrook (1941), Giersbach and Crocker (1932), Grisez (1974), Haut (1932, 1938), Havis and Gilkeson (1949), Hesse and Kester (1955), Heit (1938), Kester (1969), Koreisho and Morozov (1955), Krefting and Roe (1949), Morov and Kraebel (1937), Pollock (1959), Probocskal (1963), Roe (1941), Suszka (1964, 1967), Swingle (1939), Tukey (1924), USDA (1961).

* Seeds were in a moist medium at a constant temperature of 20 °C or at a temperature alternating diurnally from 30 °C (8 hours) to 20 °C (16 hours).
† Seeds were in a moist medium at a temperature between 0.6 °C and 5 °C; 2.8 to 5 °C was better.
‡ Germination occurred during the stratification period.
§ Results were similar at 10 °C.
ll Adequate germination was reported at unspecified temperatures.

To achieve germination greater than 90%, Seeley and Damavandy (1985) found that apricot seeds need 50 days of chilling; mazzard cherry seeds, 120 days; mahaleb cherry seeds, 100 days; and peach seeds, 90 days of chilling before germination. Zigas and Coombe (1977) reported that 10 weeks of stratification at 3 °C was enough time to remove any inhibitory properties of the testa of peach seeds. The best treatment reported for mazzard cherry seeds in Europe is alternating cold and warm stratification without medium, with seeds at 28 to 30% moisture: 2 weeks at 20 °C, 6 weeks at 3 °C, 2 weeks at 25 °C, 4 weeks at 3 °C, 2 weeks at 25 °C, then 11+ weeks at 3 °C, with the treatment ending when 40 to 50% of the seeds readily germinate at 3 °C (Suszka and others 1996).

Seeds usually are held in cold stratification until incipient germination occurs (Giersbach and Crocker 1932; Huntzinger 1968; Suszka 1967). Visible signs of incipient germination are split endocarps or emerging radicles. When the cold period was interrupted with warmer temperatures before these stages were reached, secondary dormancy was induced (Huntzinger 1971; Suszka 1967). Michalska (1982) reported a 10-week delay in root growth of mazzard cherry when a thermal induction treatment was interjected into a 3 °C chilling period. Root growth was activated only after 12 to 16 weeks of chilling at 3 °C. In a test by Suszka (1967), seedlots of mazzard cherry were stratified for 154 days at 3 °C and then separated into 3 fractions: intact seeds, cracked seeds, and those with emerging radicles. A sample of each fraction was sown separately at a depth of 1 cm ($^3/_8$ in) and subjected to a temperature of 20 °C. Epicotyls emerged from only 8% of the intact stones, but from 90% of the cracked seeds and from 95% of those with emerging radicles. The optimum temperature for epicotyl emergence from cracked seeds of European bird cherry, however, was between 5 and 10 °C (Suszka 1967). Seedlings have developed from up to 100% of cracked seeds of black cherry after sowing (Defler 1937; Huntzinger 1971).

Maximum germination, as judged by the presence of radicles at least 3 mm long, was obtained at 3 or 5 °C on seeds of apricot, mazzard cherry, myrobalan plum, garden plum, mahaleb cherry, European bird cherry, and black cherry (Suszka 1967). For many other species in table 6, temperatures somewhat higher than 5 °C were used for germination. Information is not available, however, on the proportion of seeds that had started to germinate during the cold stratification period before the temperature was raised. The diurnally alternating temperatures of 30 and 20 °C specified for *Prunus* in the International Rules for Seed Testing (ISTA 1996) apparently are much too high. The Association of Official Seed Analysts (AOSA 1996) specify a germination temperature of 18 to 22 °C for mazzard cherry and peach. ISTA (1996) rules specify 90 to 120 days of chilling for mazzard cherry, European bird cherry, and black cherry. Germination is hypogeal in many species as (figure 4), but epigeal in common choke cherry (figure 5).

Viability tests are usually preferred over germination tests because of the long stratification time required to break

Figure 4—*Prunus americanum*, American plum: seedling development at 1, 3, 5, and 9 days after hypogeal germination.

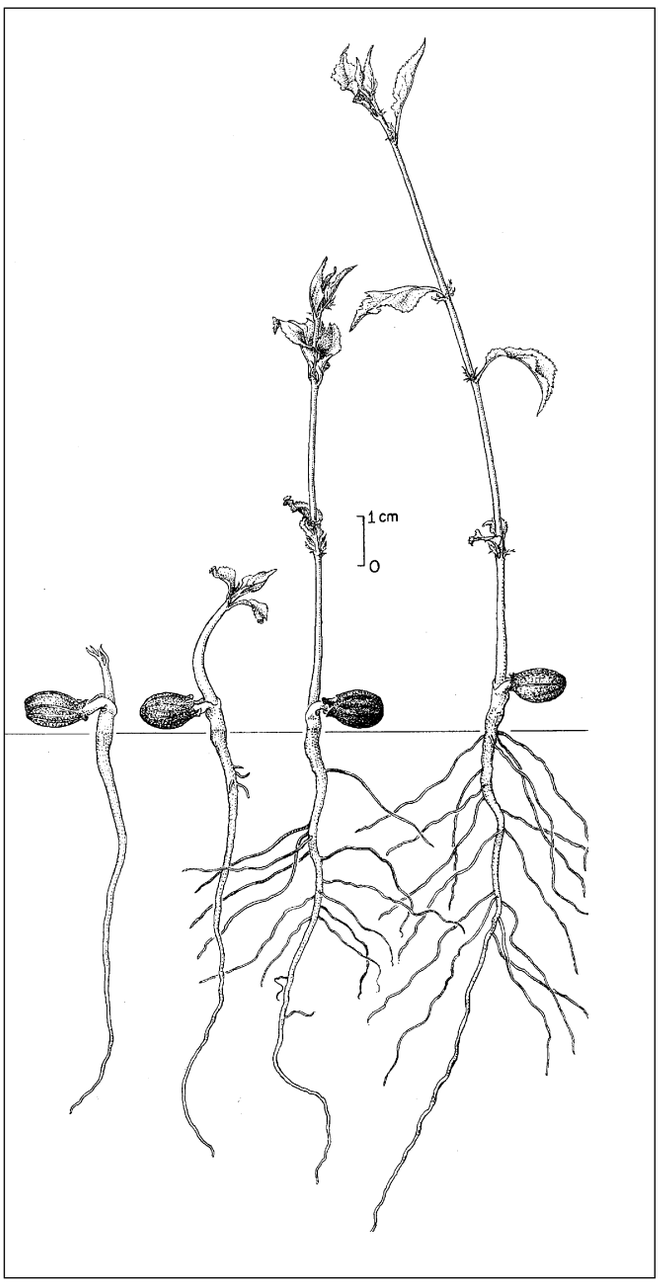
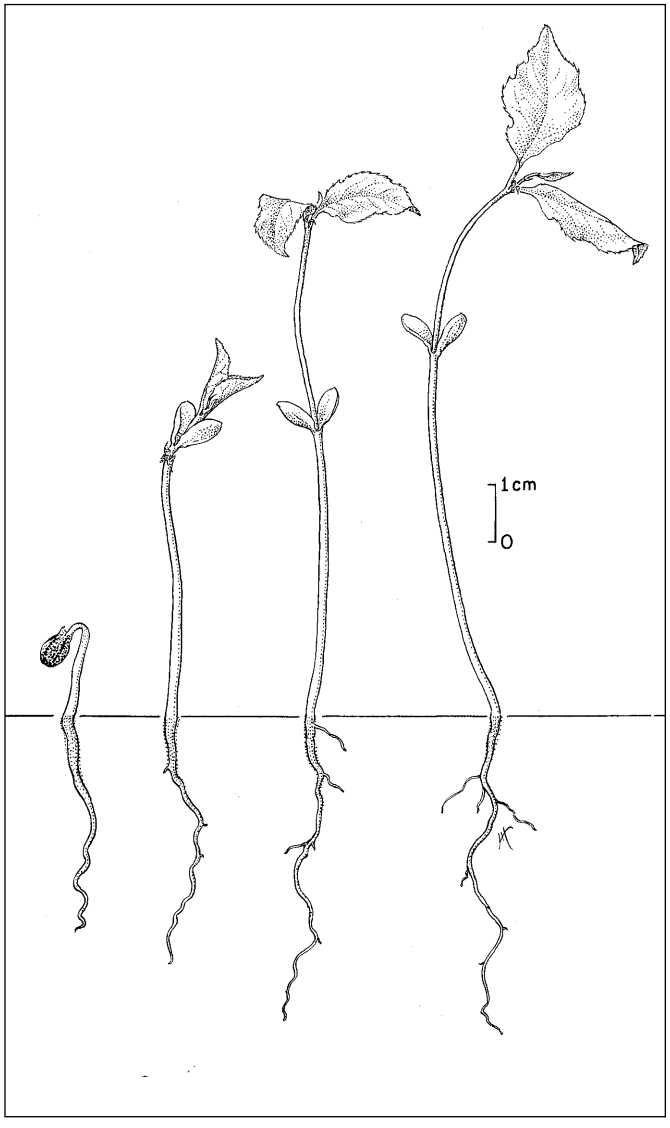


Figure 5—*Prunus virginianna,* common chokecherry; seedling development at 1, 3, 7, and 11 days after epigeal germination.



dormancy of most species. The excised embryo procedure is recommended by both AOSA (1996) and ISTA (1996) for all species, and it has been commonly used on American plum, almond, apricot, peach, sloe, and both wild and cultivated cherries (Chao and Walker 1966; Heit 1955; Shumilina 1949; Tukey 1944). Once the seedcoats are removed, the seeds are placed on dampened blotter paper in a 20 °C germinator for 10 days. The embryos are viable when the radicles begin to grow or the cotyledons turn green or open up.

The seeds of *Prunus* species also are easily stained with tetrazolium chloride, and they usually have high viability (table 6). The viability percentage is highly correlated with field emergence. Tetrazolium staining is recommended as an alternative method for viability tests on all *Prunus* species (AOSA 1996; ISTA 1996). The seed should be cracked and a small piece of cotyledon removed at the distal end, then soaked for 18 hours at 20 °C. The seedcoat should then be removed before incubation in a 1.0% solution for 8 to 12 hours at 30 °C (or 12 to 18 hours in 0.5%). Large-seeded species may require longer staining times. To be considered viable, the radicle tip and $^1/_3$ of the distal area of the cotyledons should be stained (ISTA 1996).

Nursery practice. Untreated *Prunus* seeds may be sown in the fall or stratified seeds may be sown in spring. Some species that require long periods for after-ripening are stratified warm and cool even before fall-sowing, or they may be planted as soon as collected (Al'benskii and Nikitin 1956; Grisez 1974; Koreisho and Morozov 1955). American and Chickasaw plums and common choke cherry seeds benefit from 30 days of warm stratification followed by 45 days of cold stratification before sowing (Huffman 1996). In fall-sowing, it is important to sow early enough to allow seeds to after-ripen before the ground freezes (Swingle 1925). Secondary dormancy can be induced in partially after-ripened seeds by high soil temperatures (Grzeskowiak and others 1983). Suszka (1978) recommends covering the nurserybed with 10 cm (4 in) of straw mulch. Seeds should be sown in early September, or by mid-October at the latest, in the northern states (Grisez 1974; Heit 1938, 1967; Huntzinger 1971). Mulching and deeper sowing help overcome the effects of late sowing and dry climates.

Stratified seeds should be sown as early in spring as possible because high temperatures and drying can reduce germination (Haut 1932; Huntzinger 1971; Koreisho and Morozov 1955; Suszka 1967). It is best if a high proportion of the seeds in the seedlot are cracked but have not yet begun radicle elongation (Koreisho and Morozzov 1955; Suszka 1964, 1967). Long radicles are easily broken in handling and sowing. For this reason, seeds should be checked toward the end of the stratification period for emerging radicles (Huntzinger 1968, 1971). Transparent containers are ideal for this purpose. If radicle elongation starts when it is too early to sow, the temperature should be reduced to near-freezing (Afanasiev 1942).

Normal precautions may be taken against fungi during stratification and sowing, but they do not appear necessary if seedlots are properly cleaned and handled. Rodents must be kept out of the nursery, however (Grisez 1974; Huntzinger 1971).

Prunus seedlings reach suitable planting size in 1 or 2 years. Low seedbed densities help assure adequate size the first year and reduce the proportion of culls (Grisez 1974; Stoeckeler and Jones 1957).

Seedlings may be planted 1 m (3 ft) apart in rows 3 to 4 m (10 to 13 ft) apart to produce 3,000 seedlings/ha (7,400 seedlings/ac) (Janick and Moore 1996). Seedlings that set terminal buds may be forced by gibberellin sprays or can be cut back to stimulate growth (Janick and Moore 1996). It has been observed in the nursery that apricot trees with large leaves and unbranched shoots are more likely to produce medium or large sized fruits, but plants with much branching, very thin shoots, and small leaves are likely to have small fruit and fruit at an older age (Janick and Moore 1996). Nursery practices that have been successful are listed in table 7.

Table 7—*Prunus,* cherry, peach, and plum: nursery practice

Species	Stratification periods* (days)		Seeds sown/ft²	Sowing depth (in)	Tree %	Outplanting age (yr)
	Fall-sowing	Spring-sowing				
P. americana	0–90	120	4	1–2†	33–50	1
P. angustifolia	0	15–20	1	33	1	—
P. armeniaca	0	90	9	2	50	1
P. avium	60‡	120	13	1–2	—	1 or 2
P. cerasifera	0‡	—	10	2	64§	1
P. cerasus	90‡	90	21	—	—	1 or 2
P. domestica	0	—	13	2	—	1 or 2
P. mahaleb	0–60	60	—	1–2	45§	—
P. padus	60‡	120	50	1/2–1‖	—	1 or 2
P. persica	0	85	0.75	2	—	—
P. pumila var. *besseyi*	0	120	6–7	—	77	—
P. serotina	0	120	10–20	1 1/2–2‖	7–83	1
P. spinosa	0‡	170	17–28	1–2	70–75§	1 or 2
P. tomentosa	0	60	15–30	1‖	72	1
P. virginiana	0	120–160	25	_	3–34	1 or 2

Sources: Afanasijev (1962), Al'benskii and Nikitin (1956), Bailey (1969), Bejdl (1954), Engstrom and Stoeckeler (1941), Grisez (1974), Heit (1938, 1967), Huntzinger (1971), Koreisho and Morozov (1955), Nyholm (1951), Rudolf (1961), Schaaf (1938, 1940), Shoemaker and Teskey (1959), Shumilina (1940, 1949), Stoeckeler and Jones (1957), Swingle (1939), Talbert (1946).

* Stratified in a moist medium at a temperature between 2.8 and 5 °C.

† Add a 10 to 15 cm (4- to 6-in) soil ridge to the nurserybed.

‡ Or stratify from time of collection to time of sowing when fresh seeds are used.

§ Germination percent (not tree percent).

‖ On fall-sown beds, add ~8 cm (3 in) of straw or moss for a mulch.

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Pinaceae—Pine family

Pseudotsuga Carr.

Douglas-fir

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Growth habit, occurrence, and uses. Seven species are currently included in the genus *Pseudotsuga;* they are Douglas-fir (*P. menziesii* (Mirb.) Franco) and bigcone Douglas-fir (*P. macrocarpa* (Vasey) Mayr) in North America and *P. japonica* (Shirasawa) Beissner, *P. wilsoniana* Hayata, *P. sinensis* Dode, *P. forrestii* Craib, and *P. gausseni* Flous in eastern Asia (Hermann 1982; Little 1979). The generic name—*Pseudotsuga,* meaning "false hemlock"—reflects the difficulties taxonomists had in classifying the genus (Little 1952).

Fossil records indicate that *Pseudotsuga* has been present in western North America since the Early Tertiary Epoch, and later also in Japan and perhaps in Europe (Hermann 1985). Its limited early range in North America expanded during interglacial intervals to approximately its current range.

Only 1 species, Douglas-fir, is widely distributed; the other 6 species are relatively sparse and their natural distributions are narrow and restricted. The range of Douglas-fir extends from latitude 19°N in central Mexico to 55°N in central British Columbia, and from longitude 97°W in Mexico northwesterly to the Pacific Ocean and to 128°W in British Columbia (Little 1971; Silen 1978). Two varieties are recognized—coastal Douglas-fir (var. *menziesii*) and interior Douglas-fir (var. *glauca*) (table 1). The 2 varieties adjoin and introgress in British Columbia (Li and Adams 1989; Rudloff 1972) but occur in separate territories from southern British Columbia southward. Bigcone Douglas-fir occurs only in southwestern California and is separated by 34 km from the southernmost known locality for coastal Douglas-fir (Griffin 1964). Both North American species have been propagated successfully in Europe but only Douglas-fir has gained worldwide prominence. It is the most important exotic grown in western and central Europe and is also very important in Chile, New Zealand, and Australia (Kleinschmit and Bastien 1992), becoming naturalized in several countries (Jones 1946; Ledgard 1988).

In North America, Douglas-fir naturally occupies a wide span of elevations and climatic conditions. Coastal Douglas-fir is found on soils derived from marine, glacial, and vol-

Table 1—*Pseudotsuga,* Douglas-fir: nomenclature and occurrence

Scientific name & synonyms	Common name(s)	Occurrence
***P. macrocarpa* (Vasey) Mayr** *Abies douglasii* var. *macrocarpa* Torr. *A. macrocapa* Vasey	**bigcone Douglas-fir**, bigcone-spruce, desert-fir	Mtns of SW California
***P. menziesii* var. *glauca* (Beissn.) Franco** *P. douglasii* var. *glauca* Mayr *P. menziesii* var. *caesia* (Schwerin) Franco *P. taxifolia* var. *glauca* (Beissn.) Sudworth	**interior Douglas-fir,** blue Douglas-fir, Rocky Mountain Douglas-fir, Colorado Douglas-fir, inland Douglas-fir	Central British Columbia & SW Alberta, S in mtns to N & central Mexico, from E Washington, Oregon, Nevada, & W Arizona to E Montana, Wyoming, Colorado, New Mexico, & NW Texas
***P. menziesii* var. *menziesii* (Mirb.) Franco** *P. douglasii* var. *viridis* Schwerin *P. menziesii* var. *viridis* (Schwerin) Franco *P. mucronata* (Raf.) Sudworth *P. taxifolia* (Lamb.) Britton	**coastal Douglas-fir,** green Douglas-fir, Oregon Douglas-fir, Douglas-fir, Douglas-spruce	SW British Columbia through Washington & Oregon to central California, E into Cascade & Sierra Nevada ranges to W Nevada

Sources: Griffin and Critchfield (1976), Hermann (1982), Hermann and Lavender (1990), Little (1952, 1971, 1979), McDonald (1990), Minnich (1982).

canic origins at elevations from sea level to 1,250 m in the north to 2,300 m near its southern limits in the Sierra Nevada (Hermann and Lavender 1990). Interior Douglas-fir is found on soils derived from many parent materials at elevations from 550 to 2,440 m in the north and from 1,550 to 3,260 m in southern Arizona. Bigcone Douglas-fir is also found on a wide variety of soils at elevations from 275 to 2,400 m on gentle to steep slopes (McDonald 1990). The altitudinal distribution of these species shifts from southerly slopes at high elevations or in northern parts of their ranges to northerly slopes in the southern parts in response to the interacting limitations of temperature and moisture. The presence of large canyon live oaks—*Quercus chrysolepis* Liebm.—apparently modifies fire intensity and appears to be a third crucial influence on distribution of bigcone Douglas-fir (Minnich 1977, 1980).

Both species are found in pure and mixed stands, generally as dominants or codominants, and grow to large sizes that vary by elevation and site. On favorable sites, mature bigcone Douglas-fir trees average 24 to 30 m tall and 61 cm or more in dbh; the largest living individual is 44.2 m tall and 213 cm dbh (AFA 2000). Interior Douglas-fir trees average 30 to 37 m tall and 38 to 102 cm dbh; the largest individual now on record is 42.4 m tall and 255 cm dbh (AFA 2000). Coastal Douglas-fir grows much larger; heights of 76 m and diameters of 150 to 180 cm are common on favorable sites. The largest living tree is 85.6 m tall and 408 cm in diameter (AFA 2000). The lifespan of bigcone and interior Douglas-firs is up to 400 years and that for coastal Douglas-fir about 500 years (Hermann and Lavender 1990; McDonald 1990). The recorded maximums are 622 years for bigcone Douglas-fir and 1,400 years for coastal Douglas-fir (McArdle and others 1961; McDonald 1990).

Because of its wide distribution and many desirable characteristics, Douglas-fir is a major factor in timber production, watershed protection, wildlife habitat, and aesthetics whereas bigcone Douglas-fir's contribution is primarily local and limited. Douglas-fir is the premier species used where strength is needed in construction—laminated beams and arches, timbers, poles, piling, and structural plywood—and also for general construction, fiberboard, millwork, furniture, and specialty products. It is also the leading species used in the West for sulfate pulp (Panshin and Zeeuw 1970) and for Christmas trees.

To further its propagation within and beyond its native range, Douglas-fir's genetic and regeneration traits have been studied intensively. Clinal genetic variation has been demonstrated in both the coastal and interior varieties for many traits, including survival, growth, form, phenology, insect and disease resistance, cold hardiness, wood characteristics, and chemical composition (Campbell 1986; Campbell and Sorensen 1978; Campbell and Sugano 1993; Ching and Bever 1960; Griffin and Ching 1977; Joly and others 1989; Li and Adams 1989; Read and Sprackling 1976; Rehfeldt 1979, 1989; Schowalter 1988; Silen 1978; Sorensen 1983; St. Clair and Adams 1991; Strauss and Tsai 1988). Because the survival and growth of Douglas-fir at a given location varies by the genetic source used, much effort has been expended in defining guidelines and zones for informed use of seeds and stock beyond the local geographic and climatic area of origin (Campbell 1991; Kleinschmit and Bastien 1992; Randall 1996; Rehfeldt 1981, 1983a&b.) Inspection systems have been developed to ensure that Douglas-fir seedlots and stock are correctly labeled and their origins certified (Portlock 1992; Schrumpf and Pfeifer 1993.)

Efforts to genetically improve Douglas-fir began over 50 years ago (Isaac 1949) and have developed into large long-term cooperative programs in western North America and abroad. In the Pacific Northwest, most of the seeds used in reforestation of coastal Douglas-fir now come from seed orchards (Daniels 1995). The species' use in the breeding zone of origin and other breeding zones is guided by results of outplanting tests and general rules for seed transfer (Randall 1996). A 10% gain in juvenile height growth is predicted for selections representing 6 low-elevation breeding zones in western Oregon and Washington (Stonecypher and others 1996). An international program for genetic improvement of Douglas-fir was started in 1967 and is continuing under IUFRO agencies involving 59 institutions in 36 countries (Kleinschmit and Bastien 1992). Other genetic improvement efforts involve selection for Christmas trees (Douglass and TerBush 1975; Silen 1978) hybridization (Rehfeldt 1977), and clonal propagation (Silen 1978). Many cultivars of Douglas-fir have been propagated by horticulturists (Hermann 1982).

Flowering and fruiting. Male and female strobili burst bud during late winter and spring (table 2), about a year after their initiation as axillary bud primordia (Allen and Owens 1972). Male strobili are generally borne abundantly over much of the crown on the proximal half of year-old shoots; these strobili become somewhat pendant when mature and are about 2 cm long. Female strobili develop more distally on year-old shoots that are located primarily in the upper half of the crown. The female strobili are erect at the time of pollen shedding and measure about 3 cm long; their appearance is dominated by large trident bracts (Allen and Owens 1972). The color of female strobili (seed cones) ranges from deep green to deep red, and that of male strobili

Table 2—*Pseudotsuga,* Douglas-fir: phenology of flowering and fruiting

Species	Location	Flowering	Cone ripening	Seed dispersal
P. macrocarpa	S California	February–mid-Apr	Early Aug–early Oct	Late Aug–late Oct
P. menziesii var. *glauca*	Central Colorado (elev. 2,060–2,880 m)	Mid-Apr–early May	—	—
	Montana (elev. 700–1,700 m)	Late May–early June	Late July–early Aug	Late Aug–mid-Sept*
	Northern Idaho (elev. 820–1,000 m)	Early May–late June	Mid-Aug	Early Sept*
	Central Oregon	Mid-May–mid-June	—	Mid-Aug–mid-Sept*
P. menziesii var. *menziesii*	Coastal British Columbia	Late Mar–mid-May	Aug	Sept–late Mar
	W-central Oregon & W Washington	Mid-Mar–early June†	Aug	Late Aug–late Mar‡
	S Oregon	Early Apr–early May	—	Mid-Aug*
	N California	—	August	Sept–early winter§

Sources: Allen (1942), Allen and Owens (1972), Ching and Ching (1962), Gashwiler (1969), Gause (1966), Griffith (1968), Isaac (1943), McDonald (1990, 1992), Morris (1952), Owston and Stein (1974), Roeser (1942), Silen (1963), Sorensen and Campbell (1971), Sudworth (1908).
* Beginning dates only.
† Upslope progression in pollen shedding and female receptivity averaged 23.5 m of elevation per day on 4 transects in western Oregon and Washington (Silen 1963).
‡ About 70 to 90% of the seeds usually disperse in September and October; most of the remainder disperse between November and March (Allen 1942; Isaac 1943).
§ Seedfall usually greatest in October (McDonald 1992).

from yellow to deep red. Strobili of the same sex tend to be of uniform color on individual trees, but the color of the males and females may differ (Griffith 1968).

Seed cones become receptive to pollination when they have emerged by half to two-thirds from the bud scales, and they remain so for at least 6 to 10 days (Ho 1980; Owens and others 1991; Silen 1978). Pollen dispersal occurs for 20 to 30 days in a given locality (Silen 1963). Seed cones soon become pendant, and fertilization takes place about 10 weeks after pollination (Allen and Owens 1972). Seeds develop through late spring and summer, reaching maturity in August or early September. Cones generally begin to dry and turn brown in August or September, and most seeds are released in September and October (table 2).

Calendar dates for phenological events vary with latitude and elevation (Silen 1963), between individual trees in a locality (Orr-Ewing 1956), and by position within the crown (Orr-Ewing 1956; Roeser 1942). Timing also varies from year to year, depending on weather conditions. Because cones open by drying, time of seed dispersal is particularly influenced by low humidity and drying winds in late summer and fall.

The mature cones of Douglas-fir are readily identified by their 3-lobed bracts, which protrude beyond the cone scales (figure 1). On each scale are 2 seeds that have relatively large wings (figure 2). One side of the seed is variegated light brown; the other is more glossy and dark brown. Embryos are linear (figure 3). The number of filled seeds per cone varies widely and tends to be greater for large

Figure 1—*Pseudotsuga menziesii* var. *menziessii*, coast Douglas-fir: mature, closed cones have characteristic 3-lobed protruding bracts.

cones (Willis 1917). In interior Douglas-fir, filled-seed numbers ranged from 20 to 30 per cone in some collections (Owston and Stein 1974). For coastal Douglas-fir, filled-seed numbers ranged from 4 to 54 per cone in 309 collections from individual 35-year-old trees in northwestern Oregon (Olson and Silen 1975). Numbers averaged 16 per cone in collections from 127 individual trees in 10 westside areas located from north-central Washington to south-central Oregon (Willis and Hofmann 1915) and 19.4 per cone (range 2 to 35) in collections made between 1966 and 1978

Figure 2—*Pseudotsuga*, Douglas-fir: seeds of *P. macrocarpa*, bigcone Douglas-fir (**top**) and *P. menziesii*, Douglas-fir (**bottom**); the 2 varieties of the latter bear seeds similar in appearance and anatomy.

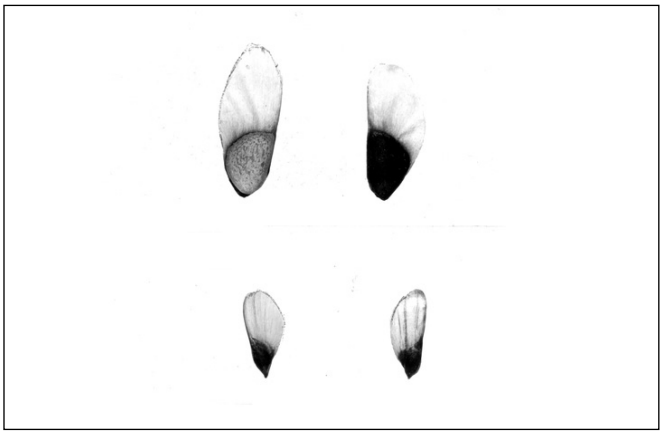
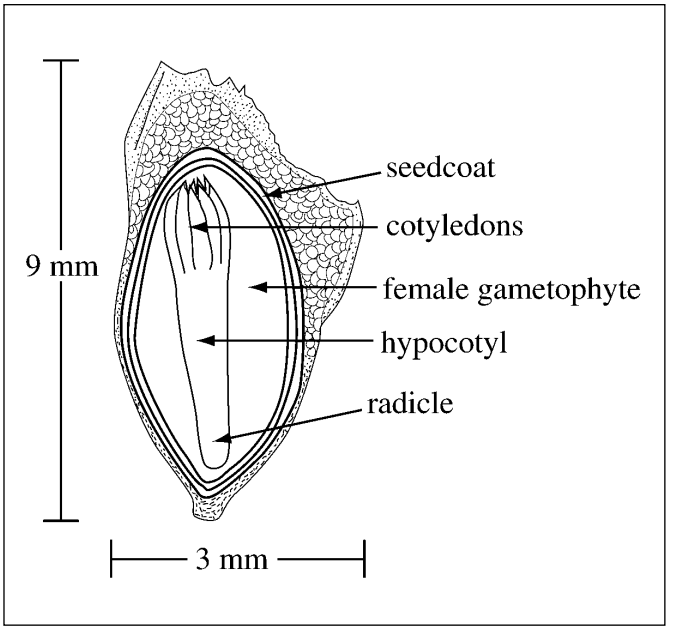


Figure 3—*Pseudotsuga menziesii*, Douglas-fir: longitudinal section through a seed showing fully developed embryo.



from 923 individual trees with sparse to good crops in 95 coastal and Cascade stands in Oregon and Washington (Sorensen 1997).

The seeds of Douglas-fir are disseminated by gravity and wind; their distribution varies widely—it is influenced by crop abundance, tree height and position, wind velocity, and other factors (Isaac 1930). Most seeds of bigcone Douglas-fir fall beneath the tree of origin; wider dissemination occurs primarily during high winds (McDonald 1990). Some Douglas-fir cones remain attached to the tree for a year or more after seed dispersal.

Seed production in Douglas-fir is highly variable from tree to tree. In a good seed year, an average mature, forest-grown coastal Douglas-fir produces about 0.45 kg (1 lb) of cleaned seeds (Isaac 1943), whereas widely spaced trees may produce 0.91 kg (2 lb) or more (Allen 1942; Isaac 1943). Because not all trees produce seeds, stand production averages considerably less than 0.45 kg (1 lb) of seeds per tree (Isaac 1943). Trees 100 to 200 years old are most prolific, but cones on younger trees are larger and contain more viable seeds (Willis 1917; Willis and Hofmann 1915). In young stands, seed production of coastal Douglas-fir begins at 7 to 10 years of age and somewhat later for interior Douglas-fir (table 3). When cultural and chemical techniques are used to stimulate precocious flowering, seeds have been produced on 2- to 5-year-old Douglas-firs, but pollen production is sparse (Silen 1978). Bigcone Douglas-firs may bear cones beginning about age 20, but they are rare on trees less than 40 years old (McDonald 1990).

Generally, some seeds are produced annually by coastal Douglas-fir except for about 1 year in any 4- to 5-year period (Isaac 1943; Reukema 1982); however, higher crop failure rates have been reported (McDonald 1992). Stand conditions as well as environmental and internal factors make the crop cycle erratic (Baron 1969; Eis 1973; Lowry 1966; Owens and others 1991). Abundant crops have occurred from 2 to 11 years apart (table 3). The seed production cycle for interior Douglas-fir is quite similar. Bigcone Douglas-fir usually has small cone crops; abundant crops occur infrequently and usually only in localized areas (USDA FS & CDF 1955–1971).

The existence of a cone crop cannot be confirmed until about 2 months before seedfall; poor pollination, frost, cone abortion, insects, and other factors may cause widespread failure after cones are visible (Owens and others 1991). Forecasts of crop potential are possible 12 months in advance of seedfall by counts of female buds (Allen 1941) or 17 months in advance by counts of male buds (Silen 1967). Bud counts are more accurate in predicting crop failures than in forecasting successful crops.

The high economic value of Douglas-fir seeds, especially genetically improved seeds, has prompted many studies, including those on the following topics: (1) factors affecting seed set (Owens and others 1991); (2) effects of inbreeding level on filled seed production (Woods and Heaman 1989); (3) influence of reproductive phenology on genetic diversity of seed crops (Copes and Sniezko 1991; El-Kassaby and Askew 1991); and (4) differences in fruitfulness between clonal and seedling orchards (El-Kassaby and others 1989). Cultural practices to stimulate seed production in natural

Table 3—*Pseudotsuga,* Douglas-fir: height, seed-bearing age, crop frequency, and cone length

Species	Mature height (m)	Minimum seed-bearing age (yr)	Years between large seedcrops	Cone length (cm)
P. macrocarpa	9–30	20*	—	11–17
P. menziesii				
var. *glauca*	23–49	20	3–10	4–7
var. *menziesii*	27–91	7–10†	2–11	6–10

Sources: Allen (1942), Boe (1954), Gause (1966), Hermann and Lavender (1990), Lowry (1966), McArdle and others (1961), McDonald (1990), Roeser (1942), Sudworth (1908).

* Occasionally earlier on good, open sites (Gause 1966).

† The minimum age for commercial collections has been considered 20 to 25 years (Allen 1942).

stands or seed orchards include thinning and spacing (Reukema 1982, Williamson 1983); fertilization (Edwards 1986); girdling (Wheeler and others 1985; Woods 1989); top pruning (Copes 1973); and use of growth regulators alone (Ross and others 1980) or in combination with girdling, root-pruning, top-pruning, and branch-thinning (Ross and Bower 1991; Ross and Currell 1989; Ross and others 1985). In 1990, Cress and Daniels reported that existing coastal Douglas-fir seed orchards had the production potential to reforest 11 million acres with genetically improved stock by the year 2000.

Hedlin and others (1980) have developed a key for the many insects that damage cones and seeds of Douglas-fir. The Douglas-fir cone moth (*Barbara colfaxiana Kearfott*) causes major damage throughout the range of Douglas-fir but is most persistent in dry areas (Miller and Ruth 1989). As few as 3 larvae can destroy all of the seeds in a cone. The Douglas-fir cone gall midge (*Contarinia oregonensis* Foote) is another major destroyer of seeds, particularly in wet areas; severe infestations can destroy an entire crop. The Douglas-fir seed chalcid (*Megastigmus spermotrophus* Wachtl.) is found on both Douglas-fir and bigcone Douglas-fir and frequently destroys 2 to 15% of the crop. Other insect pests include the western flower thrips (*Frankliniella occidentalis* Pergande), which feeds on Douglas-fir pollen in California; Douglas-fir cone scale midge (*Contarinia washingtonensis* Johnson); coneworms (*Dioryctria abietivorella* Groté, *D. pseudotsugella* Munroe, and *D. reniculelloides* Mutuura and Munroe); western conifer seed bug (*Leptoglossus occidentalis* Heidemann); and the fir cone looper (*Eupithecia spermaphaga* Dyar). The western spruce budworm (*Choristoneura occidentalis* Freeman) has also caused heavy damage to flower buds, flowers, and developing cones (Dewey 1970; Frank and Jenkins 1987).

A variety of efforts have been made to assess and curb insect damage to cones and seeds of Douglas-fir. The effects of cone and seed insects were evaluated in natural stands (Shearer 1984) and in Douglas-fir seed orchards (Schowalter and Haverty 1989; Schowalter and others 1985). Dombrosky and Schowalter (1988) suggested an inventory monitoring system to better identify causes of seed loss, and Miller (1986) described damage prediction systems to judge the need for protection from the Douglas-fir cone gall midge and other insects. Rappaport and Volney (1989) found that control of one pest resulted in increased damage from another. Insecticide treatments have been tested for protecting against all cone and seed insects (Stein and Koerber 1989; Stein and Tilden 1987; Summers and Miller 1986), and specifically from the cone gall midge and seed chalcid (Stein and Markin 1986) and the western spruce budworm (Stipe and Green 1981). The role of 2 recently identified pests, the Douglas-fir twig mining beetle (*Pityophthorus orarius* Bright) and a flightless weevil (*Lepesoma lecontei* (Casey), have also been investigated (Rappaport and Wood 1989; Sexton and Schowalter 1991).

Douglas-fir flowers, cones, and seeds are also affected by frost, small mammals, and birds. Buds, flowers, and conelets are periodically damaged by spring frosts (Roeser 1942; Silen and Keene 1969; Timmis 1977). Squirrels start clipping cones early, but they cut cones in large quantities mainly after seeds mature (Lavender and Engstrom 1956; Moore 1940; White and White 1985).

Collection of cones. Douglas-fir cones are collected from untended natural stands; from natural stands tended for seed production; from seed orchards; and even from trees growing in yards, playgrounds, and parks. The scope of collection ranges from a few cones for scientific or personal purposes to region-wide collections to achieve technical or commercial objectives. Thus, collection techniques range from simple hand methods to highly mechanized efforts with commensurate preharvest planning and organization

(Brown 1983; Maxwell and Aldhous 1967). Whatever the size of the collection, the same key considerations are involved—where, when, and how to collect and how to care for the cones afterward.

With 2 varieties to choose from and demonstrated genetic, geographic, and ecologic adaptation within each, choosing the right source from which to collect Douglas-fir cones is complex. Fortunately, the general axiom to collect seeds from sources ecologically similar to where they are to be used has been implemented by designation of seed zones (Rudolf 1974; Stein and others 1986) and development of seed transfer guidelines (Campbell 1986, 1991; Campbell and Sugano 1993; Randall 1996; Rehfeldt 1981, 1983a&b). Though much less is known about genetic variation in bigcone Douglas-fir, the same attention should be given to ecologically matching the seed source to the planting location.

Seeds are sufficiently ripe and ready for collection from 3 to 4 weeks before cones begin to open and shed seeds (Allen 1958a; Finnis 1950; Rediske 1969). This short collection period may start as early as August at low elevations and latitudes and as late as October at high elevations and latitudes (table 2), and it also varies with yearly weather conditions and from tree to tree (Allen 1958a; Brown 1983).

In general, cone color is not a good indicator of seed ripeness; browning of the external bracts is more diagnostic (Ching and Ching 1962). Ripeness is best determined by cutting cones open to reveal the seeds' color and appearance. The seedcoat should be golden brown to dark brown and the seed-wing light brown to tan; the endosperm should be full and firm; and the embryo should be yellowish green and fill most of its cavity (Brown 1983; Ching and Ching 1962; Finnis 1950; Willis 1917). Sample cones are cut longitudinally to check on seed ripeness and estimate seed yield. The count of filled seeds visible on one cut surface multiplied by 4.5 approximates the number of filled seeds per cone (Olson and Silen 1975). An average of 5 filled seeds per cut surface is generally needed for an economic large-scale harvest; lesser yields may be sufficient when supplies are scarce or only minor quantities are needed (Douglass and TerBush 1975; Portlock 1996; Schaefer and Miller 1985).

Douglas-fir cones are collected from standing trees, from felled trees or tops, and from squirrel caches. A whole array of spurs, ladders, cable methods, lifts, and axillary devices are used to assist climbers in getting into the crowns of tall trees and safely collecting cones (Matusz 1964; Portlock 1996). Vehicle-mounted lifts are often used in seed orchards. Shaking the cones from trees has been accomplished without serious crown damage (Copes 1985; Copes and Randall 1983; USDA FS 1972). Cost-effective methods have been devised to aerially rake crowns or clip tops by helicopter (Camenzind 1990; Wallinger 1985). Gathering squirrel-cut cones from the ground or from caches is still a key method of obtaining cones from tall trees in natural stands (Brown 1983; Maxwell and Aldhous 1967; White and White 1985). Squirrel caches provide a means of extending the harvest season, as the cones are usually cached in moist areas and remain closed. However, damage from molds may be greater than in cones harvested from trees. Silvicultural and practical advantages and disadvantages of each collecting method have been summarized by Edwards (1985).

Picked cones are bagged, then transported either first to a collection station or directly to a processing plant where they may be held before seeds are extracted, cleaned, and stored. Two concerns are paramount: keeping the collected cones adequately identified and ensuring good ventilation to prevent killing seeds from overheating or molding. A label on the inside and outside of each bag or container should at least indicate the species, geographic location, elevation, date, and signature of the collector (Stein and others 1986). Plastic mesh bags are preferred over burlap sacks because of better aeration and thus decreased likelihood of contamination by molds. To facilitate air circulation and cone expansion, bags are usually filled only half full, loosely tied, and kept in shade on racks at field sites, collection stations, and even during transport (Brown 1983).

Cones may be stored for 2 to 4 months under dry, well-ventilated conditions without impairing seed viability (Bloomberg 1969; Lavender 1958; Rediske 1961; Rediske and Shea 1965). In fact, under good cone storage conditions, seeds may benefit from after-ripening (Bloomberg 1969; Rediske 1961), whereas lengthy storage of green cones under warm moist conditions can result in severe seed losses from increased molding (Rediske and Shea 1965). Because of tree-to-tree variation in time of seed ripening, any broad-scale collection contains cones with immature seeds that need after-ripening (Allen 1958a; Olson and Silen 1975; Rediske 1961; Silen 1958). Currently, some processors after-ripen cones in well-ventilated, refrigerated vans at temperatures of 7 to 10 ºC (Lippitt 1996). Air-drying cones in protected, well-ventilated storage for several weeks or longer is more common, however (Brown 1983; Schaefer and Miller 1985).

Extraction, cleaning, and storage of seeds. At most extractories, Douglas-fir cones are at least partially air-dried during storage, then kiln-dried to fully open them. Where warm, low-humidity conditions prevail, air-drying may be sufficient, but in much of the West, some supplemental heat is necessary. Slow drying at moderate temperature is recom-

mended (table 4), as high heat applied to green cones and seeds of high moisture content can be very damaging (Allen 1958b; Hall 1984; Morris 1936; Willis 1917). Cones may be moistened just before kiln-drying to overcome any case-hardening and to facilitate a uniform rate of drying (Brown 1983). Cones of coastal Douglas-fir open fully with loss of 35 to 51% of their wet weight (Willis 1917).

Seeds are extracted from fully open cones in a variety of tumbling devices, ranging from a hand-turned, screen-covered wooden frames to large rotary combination dryer-tumblers (Stein and others 1974). Because both heat and sharp impacts can damage Douglas-fir seeds (Allen 1958b), loose seeds are often removed at several stages of processing—before kiln-drying, during drying, and during tumbling. A seed moisture content of 7.5% (wet weight basis) or less is sought during kiln-drying or by later supplemental conditioning (Brown 1983).

Post-extraction processing of seeds usually includes (1) screening to separate seeds from cone scales, dirt, and debris, (2) de-winging, and (3) fanning or blowing to remove hollow seeds, wings, and dust. Vibrating, air, or gravity separators; soaking and drying; and other methods may be used to get seedlots extra clean (Hergert and others 1971; Lowman 1975; Sweeney and others 1991). Elimination of small seeds by sizing is not recommended, however, as this reduces genetic diversity (Silen and Osterhaus 1979). In every stage of cleaning, sharp impacts need to be minimized to produce Douglas-fir seedlots of highest quality (Allen 1958b). An attainable processing standard for Douglas-fir is 98% for purity and 80% or higher for viability (Brown 1983; Lippitt 1996; Stein and others 1986).

Cone sizes and seed weights of Douglas-fir vary by variety, year, geographic location, elevation, aspect, stand age and density, tree and family, and time of collection (Hermann and Lavender 1968; Kozak and others 1963; Olson and Silen 1975; Silen and Osterhaus 1979; Sorensen 1967, 1980, 1983; St. Clair and Adams 1991; Willis and Hofmann 1915). Bigcone Douglas-fir has much larger cones and yields more seeds per weight of cones (table 4). Its smallest seeds average 5 times the weight of the largest seeds of interior and coastal Douglas-firs (table 5).

For coastal Douglas-fir, the number of cones per volume ranged from 977 to 5,067/hl (344 to 1,784/bu) in collections from 309 individual 35-year-old trees (Olson and Silen 1975); in collections from 127 individual 15- to 600-year-old trees, cones per volume ranged from 1,988 to 5,441/hl (700 to 1,916/bu) (Willis and Hofmann 1915). For both coastal and interior Douglas-fir, size of seeds tends to decrease from southern to northern latitudes, that is, to increase in number per weight (table 5). Douglas-fir seeds near the coast tend to be smaller than those from further inland, and seeds from lower elevations are sometimes smaller than those from higher elevations (Griffin and Ching 1977; Hermann and Lavender 1968; Lippitt 1996; Sorensen 1967, 1983; Sorensen and Miles 1978; Sweet 1965). Seeds produced in a seed orchard from trees of coastal Oregon origins were similar in weight to those produced by trees in untended stands (table 5).

Seeds of Douglas-fir are usually stored at or near –18 °C at moisture contents of 5 to 9% (wet weight basis) in sacks or plastic-lined fiberboard drums (Brown 1983; Stein and others 1986). Viability of good seedlots can be maintained for many years under these storage conditions; 85 to 87% germination of several coastal Douglas-fir seedlots has been maintained for 27 years (Lippitt 1996). Moderate to good seed viability has been maintained for varying lengths of storage around 0 to 5 °C, but viability declines rapidly in storage at room temperature and at high moisture content (Allen 1957, 1962a; Barton 1954; Schubert 1954).

Pregermination treatments and germination tests. Pregermination treatment of Douglas-fir seeds strongly influences their subsequent response to various germination conditions. Most seedlots benefit from stratification, but some do not require stratification, some are harmed by it,

Table 4— *Pseudotsuga,* Douglas-fir: cone drying schedules and seed yield data

Species	Cone drying schedule			Cone wt/cone vol		Seed yield		
		Kiln-drying				Seed wt/cone vol		Ratio seed wt/
	Air-drying (days)	Time (hr)	Temp (°C)	kg/hl	lb/bu	kg/hl	lb/bu	100 cone wt
P. marocarpa	8–10	—	—	32–39	25–30	1.03	0.8	2.8
P. menziesii								
var. *glauca*	4–60	2–10	38–43	32–77	25–60	0.65–1.03	0.5–0.8	1.0–1.3
var. *menziesii*	8–60	16–48	32–43	39–64	30–50	0.26–1.03	0.2–0.8	0.5–2.0

Sources: Brown (1983), Owston and Stein (1974), Radcliffe (1952), Swingle (1939).

Table 5—*Pseudotsuga,* Douglas-fir: cleaned seeds per weight

Species & location	Average /kg	Average /lb	Range /kg	Range /lb	Samples[a]
P. macrocarpa					
S California	7,145	3,241	6,137–8,115	2,800–3,681	2
S California	7,716	3,500	6,614–9,921	3,000–4,500	2
S California	11,001	4,990	9,259–13,927	3,460–6,317	3
S California	6,748	3,061	—	—	1
P. menziesii var. *glauca*					
Arizona	70,768	32,100	52,911–75,619	24,000–34,300	8
New Mexico	83,555	37,900	72,312–90,830	32,800–41,200	8
Colorado	85,539	38,800	73,414–96,122	33,300–43,600	33
Montana	88,405	40,100	79,807–99,869	36,200–45,300	14
E Washington	102,354	46,427	101,834–103,093	46,191–46,762	3
British Columbia	97,665	44,300	62,832–117,506	28,500–53,300	19
British Columbia	119,905	54,388	104,166–163,398	47,249–74,116	23
P. menziesii var. *menziesii*					
Coastal California					
Fog-belt	86,882	39,409	80,257–104,058	36,404–47,200	4[b]
Inland	70,028	31,764	55,618–78,493	25,228–35,604	5[c]
California	71,752	32,546	33,951–116,845	15,400–53,000	41
N California	67,250	30,504	40,858–109,171	18,409–49,519	20[d]
California					
Zones 090	72,305	32,797	63,268–93,268	28,698–42,605	62
Zones 300	65,538	30,181	54,780–81,359	24,848–36,904	29
Zones 500	56,906	25,812	48,028–69,867	21,785–31,691	37
W Oregon	76,278	34,599	58,343–99,109	26,464–44,955	8[d]
W Oregon	110,498	50,121	84,104–126,263	38,149–57,272	10
NW Oregon	99,503	45,134	69,589–182,150	31,565–82,622	309[e]
W-central Oregon	83,333	37,799	62,501–109,409	28,350–49,627	39
W Oregon	78,626	35,664	59,000–98,000	26,762–44,452	8[f]
Oregon & Washington	84,336	38,254	77,162–125,664	35,000–57,000	127[g]
Oregon & Washington	86,589	39,276	73,634–102,458	33,400–46,474	97
Coastal Oregon (seed orchard)	87,268	39,584	76,128–110,972	34,531–50,336	23
Washington Cascades	81,183	36,824	75,074–87,336	34,053–39,615	2[d]
W Washington	77,499	35,153	74,999–79,999	34, 019–36,287	2[f]
W Washington	116,822	52,990	82,576–153,845	37,456–69,783	46
British Columbia	86,999	39,462	65,001–99,999	29,484–45,359	4[f]
British Columbia	130,891	59,371	107,411–173,012	48,721–78,749	21
British Columbia	93,584	42,449	79,807–120,593	36,200–54,700	16

Sources: Allen (1942), Bialobok and Mejnartowicz (1970), Ching and Bever (1960), Griffin and Ching (1977), Heit (1968), Lippitt (1996), Olson and Silen (1975), Owston and Stein (1974), Rafn (1915), Randall (1997), St. Clair and Adams (1991), Sweet (1965), Willis and Hofmann (1915).

a Data represent seedlots of unknown size and number of trees unless otherwise noted.

b Four locations representing 41 elevation points (stands) totaling 87 trees.

c Five locations representing 44 elevations points (stands) totaling 94 trees.

d Each provenance (sample) represented by 10 trees under 50 years of age.

e Collected over the entire season (August 12 to September 15) from individual 35-year-old trees growing at 122 to 518 m of elevation.

f Each sample collected from 14 to 89 trees within a 40-km radius.

g From individual open-pollinated parent trees.

and some that need it are harmed by too lengthy stratification (Allen 1960; Allen and Bientjes 1954; Gosling 1988; Jensen and Noll 1959; Taylor and others 1993). Based on accumulated experience, seeds of coastal Douglas-fir generally require or benefit from stratification, those of interior Douglas-fir from northern sources may benefit, those from southern sources may not benefit, and the response to stratification by bigcone Douglas-fir is unknown (Allen 1960, 1962c; Heit 1968).

Stratification overcomes different degrees of seed dormancy that may be related to seed source and family, year of collection, cone and seed drying conditions, length and kind of storage, and other causes (Allen 1960; Allen and Bientjes 1954; El-Kassaby and others 1992; Jensen and Noll 1959; Sorensen 1991). Several pretreatments used with or in lieu of stratification also stimulate germination or reduce pathogen damage. These include a light rinse with cold or hot water, fungicide, bleach, hydrogen peroxide, ethanol, polyethylene glycol, or ethylene (Borno and Taylor 1975;

Ching 1959; Dumroese and others 1988; James and others 1988; Li and others 1994; Paci 1987; Shearer and Tackle 1960; Trappe 1961; Wenny and Dumroese 1987).

For seedlots that benefit, stratification speeds the rate of germination; for many, it also increases total germination (table 6). Although the increase in total germination was often not large, it occurred in 76.1% of samples submitted for standard service testing (Jensen and Noll 1959). The increase in germination may be substantial after lengthy stratification when seeds are tested at low temperatures or have been produced in seed orchards (Allen 1960, 1962c; Campbell and Sorensen 1984; Jones and Gosling 1994; Muller and others 1999; Sorensen 1991). Even small gains are important when using valuable improved seeds.

Douglas-fir seeds are usually stratified "naked," that is, without medium. For testing, dry seeds are often placed directly on the moistened substratum in a closed dish, or soaked in tap water for 24 hours, drained, and then placed in a closed container or bag to prechill at 2 to 5 °C for 3 weeks (AOSA 2001).

The official germination test procedures for both coastal and interior Douglas-firs require paired samples—one prechilled for 21 days at 2 to 5 °C and one not—then subjected to alternating day and night temperatures of 30 °C for 8 hours and 20 °C for 16 hours, with light at least during the high temperature period (AOSA 2001; ISTA 1996). Test duration is 21 days. A variety of absorbent blotters and other materials may be used as substratum—Sponge Rok®, vermiculite, Terralite®, and mixtures with sand. Alternating temperatures are prescribed because these yielded the highest and most consistent germination in comparison tests (Jensen and Noll 1959). But given appropriate prechilling and germinating periods, Douglas-fir will germinate with or without light in constant temperatures from 10 to 30 °C but higher temperatures cause damage (Allen 1960, 1962c; Gosling 1988; Jones and Gosling 1994; Sorensen 1991; Wright 1931). Seed position influences rate of germination; when the side of the seed that developed against the cone scale is on top, 50% germination on a moist surface is obtained in 4.6 days versus 6.3 days for those of opposite orientation, and response varies among seeds of different geographic origin (Sorensen and Campbell 1981). Rate of germination also varies among seedlots and is not directly linked with total viability (Thomson and El-Kassaby 1993). Average germination and germinative energy data from source-paired comparisons and other test experiences are listed in table 6.

Germination conditions for bigcone Douglas-fir are relatively untested (table 6). Techniques that work well for the other Douglas-fir species may prove satisfactory.

Several methods are used to quickly appraise the quality and vitality of Douglas-fir seeds when approximations are adequate or time is too short for germination tests. Determining viability by a tetrazolium (TZ) test is officially recognized and standard procedures have been designated (AOSA 2000). Seeds are soaked in water at room temperature (20 to 25 °C) overnight, then sliced longitudinally,

Table 6—*Pseudotsuga,* Douglas-fir: stratification periods, germination conditions, and results

Species	Stratification* (days)	Germination conditions: Moist medium	Temp (°C): Day	Temp (°C): Night†	Germination conditions: Days	Germinative energy: Amt (%)	Germinative energy: Time (days)	Germ. capacity (%): Avg	Germ. capacity (%): Range	Germ. capacity (%): Samples
P. macrocarpa	28	Vermiculite	30	20	28	—	—	31	—	3
	—	—	—	—	100	14	60	28	14–36	3
	—	Sand	27	21	20–90	—	—	30	15–57	5
P. menziesii	21	Sponge Rok®	30	20	14–21	60	9	68	24–83	8
var. *glauca*	0	Sponge Rok	30	20	21–35	40	12	60	27–75	8
	30	Paper	30	20	17	70	10	78	—	3‡
	0	Paper	30	20	29	76	9	84	—	3‡
	20–40	Vermiculite	25	25	30	—	—	95	86–100	6
	0	Vermiculite	25	25	50	—	—	93	88–98	6
P. menziesii	21	Sponge Rok	30	20	14–35	55	10	81	38–95	194
var. *menziesii*	0	Sponge Rok	30	20	28–35	54	17	75	29–93	194
	20–40	Vermiculite	25	25	30	—	—	87	34–100	20
	0	Vermiculite	25	25	50	—	—	84	42–100	20
	28	—	30	20	28	—	—	84	66–98	129

Sources: Allen (1962c), Lippitt (1996), Owston and Stein (1974), Rafn (1915).

* Seeds stratified "naked" (Allen and Bientjes 1954) or on moist Sponge Rok, vermiculite, or paper at 0 to 5 °C.

† Alternating temperatures included 8 hours of light during the high temperature period; light apparently was provided with constant temperature.

‡ Var. *glauca* from north-central Colorado seed sources.

soaked in a 1% TZ solution at 30 to 35 °C for 4 to 6 hours (or longer at lower temperatures), and evaluated. Healthy endosperm and embryo tissue stains uniformly pink to red. Vitality can also be determined by 2 other tests. In the one test, embryos are excised and placed in conditions favorable for growth for several days (Heit 1955); in the other test, radicle tips are cut and the seeds soaked in weak hydrogen peroxide solution under conditions that promote radicle elongation (Ching and Parker 1958). In a visual test, the oldest and simplest, seeds are cut open to determine if they are full or empty, insect damaged, or shriveled and their quality judged by the appearance and color of the endosperm and embryo; this test is still useful for a quick evaluation, particularly in the field. Seeds can be evaluated non-destructively from x-ray views, which can reveal full, empty, shriveled, and insect-filled contents, as well as any damage to the seedcoat and interior (Belcher and Vozzo 1979). Estimates of Douglas-fir seed viability are now similar if measured by x-radiography and by germination, TZ, or hydrogen peroxide testing (Hardin 1981).

Nursery practices. Millions of Douglas-fir seedlings are grown in both bareroot and container nurseries. Bareroot production predominates in the United States; container production predominates in Canada. Many sizes of seedlings are produced, ranging from small 1+0 to 3+0 bareroot stock; 1-year-old container (plug) stock; and 1+1, 1+2, 2+1, 2+2, or plug+1 transplants. Use of 1+1 transplants is now very common and plug+1s are gaining attention. Extra large stock is often used to combat animal damage or competing vegetation and for restoration plantings in riparian areas.

Technology for the production of Douglas-fir seedlings is detailed and varies by nursery and the type and size of stock to be produced. Careful management of growing-medium fertility and drainage in both bareroot and container nurseries is critical for growth and hardiness of Douglas-fir. The factors and specific techniques involved in producing bareroot Douglas-fir seedlings are presented in the Forest Nursery Manual (Duryea and Landis 1984); those for containers in the multiple-volume Container Tree Nursery Manual (Landis and others 1989, 1990a&b, 1992, 1995). The concept and practices for producing seedlings with morphological and physiological characteristics targeted for specific field conditions were brought together in a symposium (Rose and others 1990).

Production and grading practices have the potential of influencing the genetic composition as well as the physical characteristics of the seedling populations produced (Campbell and Sorensen 1984; El-Kassaby and Thomson 1996; Sorensen and Campbell 1993; St. Clair and Adams 1993). Thus, every nursery practice needs scrutiny to avoid severely altering the intrinsic characteristics for which each seedlot is valued.

Both bareroot and container nurseries usually sow stratified seeds as early in late winter or spring as possible to maximize growth and vigor of first-year seedlings (Sorensen 1996). Fall-sowings can produce even larger seedlings, but the risk of seed losses over winter from natural causes is usually too great (Duryea 1984). Before sowing outdoors or in containers, seeds are commonly soaked in tap water at 10 to 22 °C for 24 to 48 hours, drained of excess water, perhaps surface-dried, and then prechilled in 2-kg (5-lb) quantities per plastic bag in a cooler at 1 to 5 °C (Allen 1962b; Allen and Bienjes 1954; Johnson 1983; Tanaka 1984). A breather tube may be inserted in the neck of the bag and such intermediate tending as rinsing, addition of water, and turning may be done during 28 to 60 or even 90 days of stratification. Results from germination tests help guide the choice and length of pretreatments applied to individual seedlots. Germination is epigeal (figure 4).

When necessary, stratified Douglas-fir seeds can be stored for later use. Stratified seeds that were air-dried and stored at relatively high moisture content at 2 °C for 3 months or oven-dried to 7 to 15% moisture content and

Figure 4—*Pseudotsuga menziesii* var. *menziesii, coast* Douglas-fir: epigeal seedling development at 2, 5, 8, and 22 days after emergence from a peat moss–vermiculite potting mixture.

stored at –7 to 3 °C for 9 months or more retained the viability and stratification effect (Allen 1962b; Belcher 1982; Danielson and Tanaka 1978; Jones and Gosling 1994; Muller and others 1999). In other trials, viability was retained by partial drying of stratified seeds followed by low temperature storage, but the stratification effect was lost (Hedderwick 1970; Malavasi and others 1985). Seeds cannot be held in stratification indefinitely; seeds of some lots will deteriorate and those of others will germinate (Allen 1960; Danielson and Tanaka 1978; Sorensen 1980, 1991).

For bareroot production, most Douglas-fir seeds are drill-sown at a depth of 3 to 6 mm (0.1 to 0.2 in). The larger seeds of bigcone Douglas-fir are usually sown at a depth of 13 mm (0.5 in). Seedbed density varies depending on the stock size desired. For 2+0 Douglas-fir stock, seedling densities vary from 161 to 323/m^2 (15 to 30/ft^2); for 1+1s, bed densities of first-year seedlings range from 538 to 753/m^2 (50 to 70/ft^2) (Thompson 1984). Seedbed density has more effect on size of seedlings produced, and on their subsequent field survival and growth, than does irrigation frequency or undercutting and wrenching (Stein 1988).

Irrigation is used in bareroot nurseries to supply moisture to seeds and seedlings, prevent overheating or frost damage, promote growth, and augment other practices such as fertilizing and root wrenching (Duryea 1984). Carefully planned irrigation regimes are also used to control moisture stress, harden seedlings, and initiate dormancy. Specific irrigation regimes should be developed for each nursery and kind of stock—seedlings can be harmed by either too much or too little water.

The fertilizer mix and the timing and number of applications must also be developed for each bareroot nursery. Physical and chemical characteristics of the soil and irrigation water and the density of the seedling crop are critical influencing factors. A pH of 5.0 to 6.0 has been suggested for nurseries in the Pacific Northwest and 5.5 to 6.5 for nurseries in Intermountain region, as well as concomitant target levels for key mineral elements (Youngberg 1984). Most nurseries stop fertilizing in July or early August to promote seedling hardening (Duryea 1984).

Almost all bareroot nurseries undercut Douglas-fir seedlings to stimulate root growth in the upper soil layers (Duryea 1984). Timing, frequency, and depth vary by nursery and stock type. Eighty percent of nurseries in the Pacific Northwest also wrench the roots of Douglas-fir seedlings to promote fibrous root systems, stress and harden seedlings, control shoot height, and aerate the soil.

Many other cultural techniques including transplanting, weed and pest control, top pruning, and mycorrizhal inoculation are used to condition bareroot Douglas-fir seedlings for specific field conditions. Emphasis continues on fine tuning and evaluating seedling quality. Thus, an array of morphological and physiological tests have been developed to assess the quality of Douglas-fir seedlings (Duryea 1985; Jenkinson and others 1993; Rose and others 1993, 1997). Grading criteria and target sizes have been recognized for different types of stock (Iverson 1984), but more importantly, the trend is to specify seedlings by height and stem caliper as well as by stock type.

In containers, plantable stock can be produced in one season in greenhouses, outdoors under shade, or in the open. Douglas-fir grows well in the containers commonly used in forestry. High-quality, well-stratified seeds are particularly important in producing container-grown Douglas-fir. Other important considerations include keeping the pH of the potting mixture between 4.5 and 6.0; using growing practices that produce seedlings with tops and roots in balance; and hardening the seedlings to withstand direct sunlight and cold.

Fast growth of Douglas-fir is achieved in containers by providing greater control of the growth environment than possible in a bareroot nursery (Landis and others 1995). A precise growing regime must be developed suited to the capabilities at the individual container facility and the requirements of the stock to be produced. For example, Wenny and Dumroese (1992) describe a regime for producing interior Douglas-fir container stock at a facility in Idaho. Producing this variety in a single season requires use of artificial light to lengthen the photoperiod early in the growing season.

To produce extra hardy, compact stock, seedlings are grown in containers for the first year and in outdoor beds for a second year. The resulting plug+1 stock has a very fibrous root system and is usually larger and sturdier than 1+1 stock (Iverson 1984).

Douglas-fir is also propagated commercially by adventitious rooting of cuttings (Myers and Howe 1990; Ritchie 1991). Cuttings are rooted in 1 season, transplanted to a bareroot nursery in the fall to overwinter, and then grown for 1 year as bareroot stock. Over 5 years, stock from cuttings has performed similarly to 1+1 transplants. Cuttings from juvenile wood root better than those from older wood and have less plagiotropic tendencies (Copes 1992). Juvenile meristems are produced in quantity by accelerating first-year growth of stock plants (Ritchie 1994) or by maintaining juvenility on older trees by pruning (Copes 1992). Limited numbers of Douglas-fir emblings are produced by micropropagation techniques (Gupta and Grob 1995; Hutzell and

Durzan 1993; Tabor and others 1998). Rapid multiplication of superior genetic strains is made possible by practical vegetative propagation.

Seedling care. Whether bareroot or container-grown, Douglas-fir stock is best able to withstand the shock of lifting, storage, and outplanting when dormant, that is, after adapting to winter conditions. Midseason reductions in applying water and fertilizer, root wrenching, and other techniques are used to slow growth and enhance the normal climatic progression toward dormancy.

Because Douglas-fir seedlings are quite vulnerable, great care should be taken to minimize mechanical damage, desiccation, and molding during lifting, processing, storage, transportation, and planting. Protective practices include hydrating seedlings before lifting; minimizing exposure of lifted seedlings to direct sunlight, temperature extremes, and wind; preventing metabolic over-heating; misting during processing; storing and transporting them at low temperatures in bags or cartons with vapor barriers; and minimizing handling and exposure during field planting (Burdett and Simpson 1984).

Properly hardened Douglas-fir nursery stock can be stored for lengthy periods at temperatures just above or below freezing (Burdett and Simpson 1984; Hee 1986). Freezer storage prevents molding and some dormancy developments that would occur if seedlings were exposed outdoors (Ritchie 1987). Frozen bareroot and container seedlings should be thawed before they are planted (Hee 1986; Rose and Haase 1997).

Douglas-fir is usually outplanted any time from late fall through spring, depending on local climate. Winter and early spring plantings are usually best in areas with mild winters west of the Cascade Mountains. The planting season may extend into early summer in interior regions and at high elevations where snow lingers. Seedlings are extracted from most types of containers either before storage or before shipment to the field. Bigcone Douglas-fir was planted periodically from 1905 to 1975 in Los Angeles County, California, but results are unknown (McDonald 1990); in contrast, there is overwhelming evidence on successful plantings of coastal and interior Douglas-fir.

Nursery managers are dedicated to producing the size and vigor of Douglas-fir stock needed for an extremely wide range of field conditions. In many instances, the kind of stock required and the nursery practices needed to produce it are well defined; in some instances, however, either the stock or the field practices need improvement. Specific trials testing variations in a nursery's practices for producing stock of different sources may be needed, for example, "lifting windows" as investigated by Jenkinson and others (1993).

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Fabaceae—Pea family

Psorothamnus Rydb.

indigobush

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Other common names. dalea.

Growth habit, occurrence, and use. The indigobush genus—*Psorothamnus*—includes 9 species that are spread throughout the southwestern United States into Mexico (table 1). The majority of these shrubs are ornamental and many of them also contribute to the forage value of stock ranges. Branches of dyeweed have been used by Native Americans in southwestern Arizona and southern California for dye, medicine, and basket construction (Bean and Saubel 1972; Kearney and Peebles 1951).

Flowering and fruiting. Flowering occurs during the summer months (Benson and Darrow 1954). Calyx lobes are usually unequal, with the upper pair often largest. Petals emerge from the receptacle in violet, blue, or purple and white together (Jepson 1993). Fruits are indehiscent, included in or protruding from the calyx. The fruits are usually glandular and produce just 1 seed (figures 1 and 2) (Jepson 1993).

Seed collection can begin in July and continue through September for Schott dalea and smoketree as seeds get plump and change color (CALR 1993). Insect-infested seeds on the ground should be avoided. Seeds of this genus are orthodox in storage behavior and have been stored successfully under a variety of conditions (table 2).

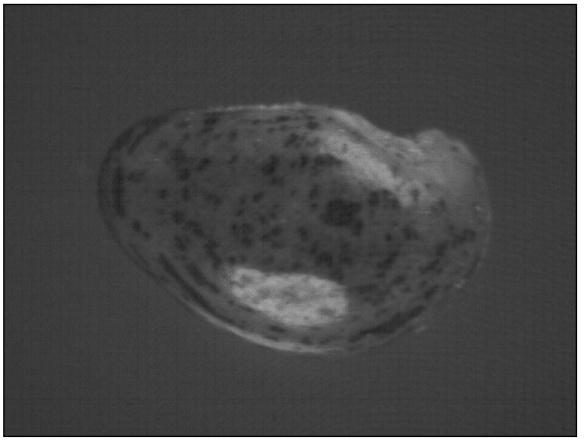
Table 1—*Psorothamnus,* indigobush: nomenclature and occurrence

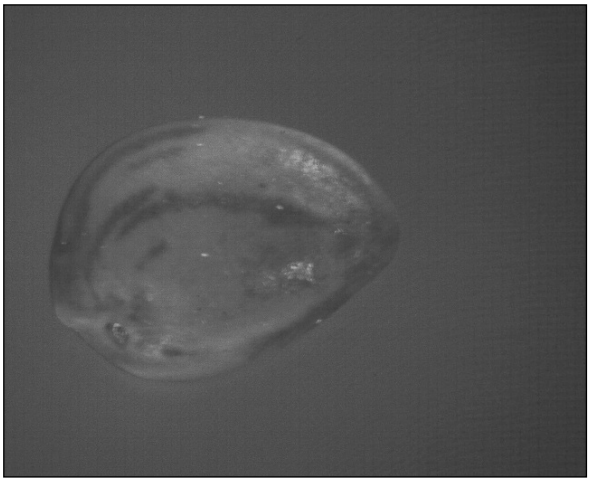
Scientific name & synonyms(s)	Common name(s)	Occurrence
***P. arborescens* (Torr. ex Gray) Barneby** *Dalea arborescens* Torr. ex. Gray. *Parosela arborescens* Heller *Parosela neglecta* Parish	**indigobush,*** Mojave dalea	San Bernadino Mtns, Mojave Desert, S Nevada, Mexico
***P. arborescens* var. *arborescens* (Torr. ex Gray) Barneby**	**Mojave indigobush,** Saunder dalea	SW Mojave Desert, Mexico
***P. arborescens* var. *minutifolius* (Parish) Barneby**	**Johnson dalea**	Mojave Desert, S Nevada
***P. arborescens* var. *simplifolius* (Parish) Barneby** *P. californica* *Dalea californica* S. Wats.	**California dalea**	Mojave Desert & San Bernadino Mtns.
***P. emoryi* (Gray) Rydb.** *Dalea emoryi* Gray	**dyeweed,*** dyebush	Mojave & Sonoran Deserts
***P. fremontii* (Torr. Ex Gray) Barneby** *Dalea fremontii* Torr.	**Fremont dalea**	Desert mtns to S Utah, Arizona
***P. polydenius* (Torr. ex S. Wats.) Rydb.**	**Nevada dalea,** Nevada smokebush	Mojave Desert
***P. schottii* (Torr.) Barneby** *Dalea schottii* Torr.; *Parosela schottii* Heller	**indigobush**, Schott dalea	Sonoran Desert of Arizona & Mexico
***P. spinosus* (Gray) Barneby** *Dalea spinosa* Gray; *Parosela spinosa* Heller	**smoketree,** smokebush	California deserts to Arizona & NW Mexico

Sources: Jepson (1993), Munz (1962, 1974).

* Despite the name, not a source of true indigo dye.

Figure 1—*Psorothamnus*, indigobush: seeds of *P. arborescens* var. *simplifolius,* California dalea (**top**); *P. schottii*, indigobush (**center**); *P. spinosa*, smoketree (**bottom**).





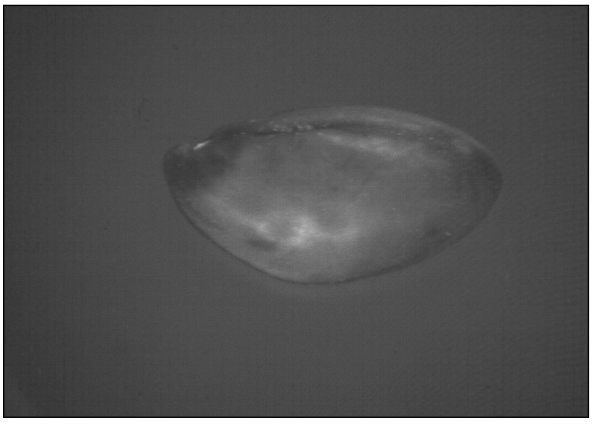
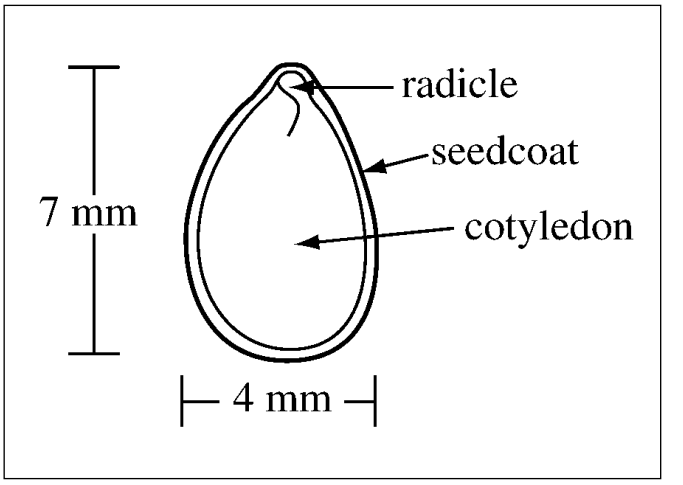


Figure 2—*Psorothamnus arborescens* var. *simplifolius,* California dalea: longitudinal section through a seed.



Pregermination treatments and germination tests. Various seed treatments have been used at the Native Plants Nursery of the U.S. Department of the Interior National Park Service's Joshua Tree National Park (JTNP); however, Emery (1988) does not suggest any pre-treatments. At JTNP, Schott dalea has been germinated by clipping and leaching seeds for 12 to 24 hours, with an average germination rate of 50%. Success with smoketree using a soak in 1:1 bleach–water solution for 30 minutes, followed by leaching for 3 to 4 hours, has resulted in an average germination rate of 40% (CALR 1993).

Other trials by Kay and others (1988) (table 2) refer to initial germination of seeds using 4 replications of 100 seeds each wrapped in damp paper toweling and stored in a growth chamber at 15 °C. Test conditions were maintained for 28 days, with germination percentages recorded every 7 days. Germination tests, conducted annually to test the effects of storage, were then averaged to a "best germination." These annual tests consisted of 4 replications of 50 seeds using the same initial testing methods.

Nursery practice. Seedlings can be successfully grown in a variety of containers. At JTNP, Schott dalea and smoketree have been successfully grown in tubes that are 76 in (30 in) long and 15 cm (6 in) in diameter and 36 cm (14 in) high and in 3.8-liter (1-gal) containers. Outplanting survival has been moderate, depending on rainfall and planting conditions (CALR 1993).

Seedling care. Seedlings can be very susceptible to damping-off. Keeping seedlings where air circulates freely and avoiding over-watering will help boost survival (CALR 1993).

Table 2—*Psorothamnus,* indigobush: seed weight, initial and best germination, and storability of seeds

Species	Seeds/weight /kg	Seeds/weight /lb	Percentage germination Initial	Percentage germination Best	Storability
P. emoryi	600	275	58	75	Stores well
P. fremontii	35	16	41	97	50% hard seed, stores well
P. polydenius	460	210	2	99	90% hard seed, stores well
P. schottii	22	10	90	88	Good storage
P. spinosus	50	23	22	58	17–47% hard seed, stores well

Source: Kay and others (1988).

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Rutaceae—Rue family

Ptelea trifoliata L.

common hoptree

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Synonym. *P. trifoliata* var. *mollis* Torr. & Gray.

Other common names. wafer-ash, hoptree, woolly common hoptree.

Growth habit, occurrence, and use. Hoptree—*Ptelea trifolia* L.—is a shrub or small tree up to 7.5 m tall with some value for wildlife, shelterbelt, and environmental plantings. It occurs from Connecticut and New York to southern Ontario, central Michigan, and eastern Kansas; south to Texas; and east to northern Florida (Little 1953). The shrub is distributed primarily along waterways in moist forests and successfully colonized sand dunes along Lake Michigan (McLeod and Murphy 1977a). In Canada, common hoptree occurs primarily in sand on the windward side of beaches along Lake Erie (Ambrose and others 1985). Hoptree propagates sexually through seed germination on adverse beach sites because 93% of annual precipitation occurs during the growing season. The species has been cultivated since 1724 (Rehder 1940).

Flowering and fruiting. Common hoptree is an obligate entomophilous, polygamo-dioecious plant. Sex ratios are skewed toward maleness, with a 60 to 40 ratio in a population (Ambrose and others 1985).

The white flowers bloom from April in the Carolinas (Fernald 1950; Radford and others 1964) to July in the North (Fernald 1950). Flowers are formed on terminal cymes with 2 ovaries, 2 stigmas, and 3 to 5 stamens (McLeod and Murphy 1977a; Radford and others 1964). Male flowers produce copious amounts of pollen grains; whereas underdeveloped staminodes of females flowers produce no pollen (Ambrose and others 1985).

Male plants have 3.7 times the amount of floral tissue for reproduction as do female plants, as determined by floral area (Ambrose and others 1985). Despite that, there is a slight (but not significant) skewness toward female flower preference by insects (Ambrose and others 1985).

In southern Ontario, over 102 insects from nearly 40 families visited hoptree plants. Hoptree was found to be the primary host for the rare giant swallowtail— *Papthо creshontes* Cramer (Ambrose and others 1985). Insect pollinators show little preference between female and male plants.

Fruits are reddish brown, orbicular, 2-seeded samaras (figures 1 and 2) that ripen from June to November (Rehder 1940) and may persist until spring (Van Dersal 1938). The seedcoat is composed of a black, crisp outer layer with a thin, brown membranous inner layer (Ambrose and others 1985). The samara is 1.5 to 2.5 cm broad and weighs from 0.026 to 0.067 g (Radford and others 1964). Most fruits only contain 1 seed, but 10% of them may contain 2 seeds. Hoptree is an abundant seeder and the samaras are dispersed by wind. Annual fruit production is about 300,000 samaras per hectare. The reniform seeds are 6.4 mm long, 2.3 wide, and weigh from 0.007 to 0.012 g (McLeod and Murphy 1977a). The embryo is completely embedded in endosperm tissue.

Figure 1— *Ptelea trifoliata*, common hoptree: fruit (samara).

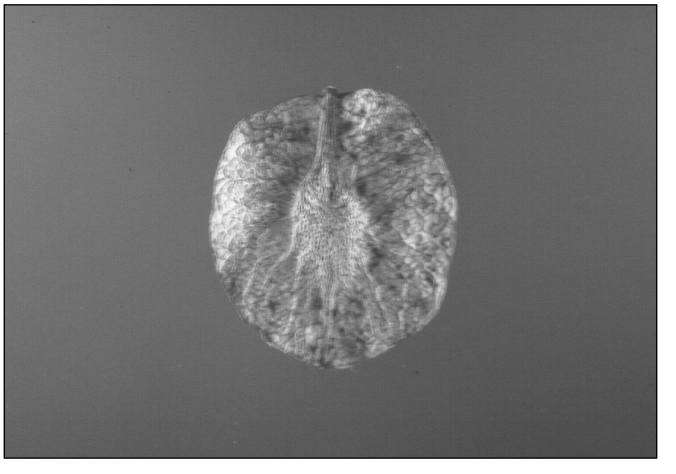
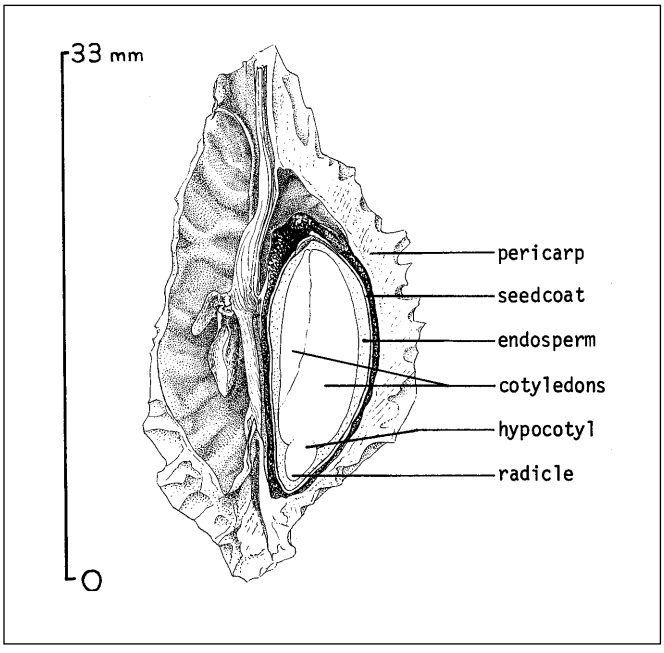


Figure 2— *Ptelea trifoliata*, common hoptree: longitudinal section through a samara.



Collection and storage of seeds. The ripe samaras may be picked from September to November. They may require a few days of drying if they are to be stored. Because samara tissue inhibits germination, removal is recommended (McLeod and Murphy 1977b). In 5 samples, the number of samaras ranged from 19,850 to 39,700/kg (9,000 to 18,000/lb) and averaged 26,500/kg (12,000/lb). About 97% of the fruits contain sound seeds.

The seeds are apparently orthodox in storage behavior—if stored in sealed containers at 5 °C, common hoptree seeds will retain most of their viability for at least 16 months. Seedlot viability determined by the 2,3,5-triphyenyl tetrazolium chloride test was over 90% after 220 days of storage at room temperature and remained over 95% during monthly checks while the seeds were being stratified (McLeod and Murphy 1977b). Viability remained at 90% when seeds were subjected to lower temperatures during germination; higher than optimum temperatures reduced viability to 45% (McLeod and Murphy 1977b).

Germination tests. Hoptree seeds have numerous barriers to germination. No germination resulted from whole fruits, punctured fruits, or whole seeds that were left unstratified (McLeod and Murphy 1977b). Unstratified embryos develop into physiological dwarfs with very short internodes and a low-vigor radicle, suggesting embryo dormancy. Excising the embryo yielded 39.5% germination; removing the seedcoat, 17%; and removing the endosperm covering the radicle, 25% (McLeod and Murphy 1977b). Endosperm tissue is a barrier to radicle elongation, not a dormancy mechanism.

Leachates of fruit parts, diluted 50, 20, 10, and 4%, applied to embryos inhibited development. Of embryos exposed to 5 ml of leachate, only 9% of those exposed to seedcoat leachate germinated; 33% to samara leachate; 45% to endosperm leachate; and 58% to no leachate (McLeod and Murphy 1977b). Stratification negated the effect of the samara leachate on embryo germination (92%) versus the control values (100%).

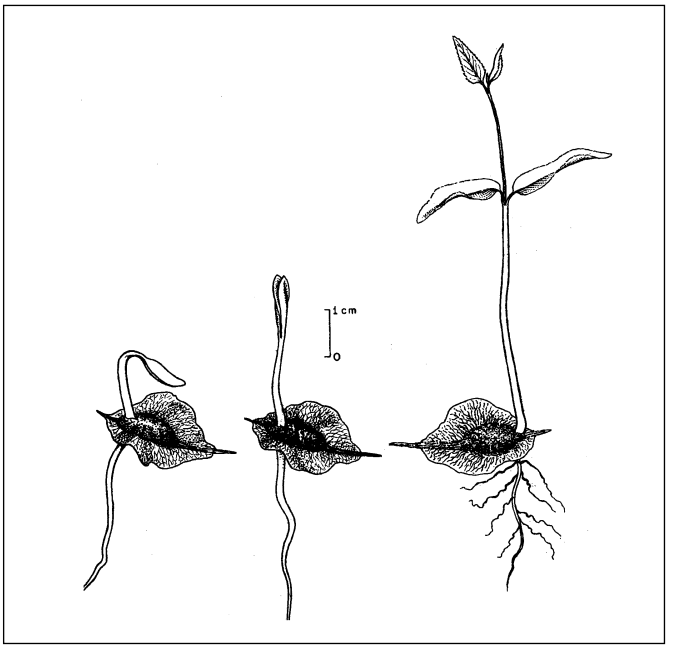
Seeds must be stratified to germinate. Artificial stratification (3 °C) is only successful when the samara is removed. Seed germination of intact fruit was 6% after 211 days of cold stratification; without the samara the germination jumped to 81% after 181 days of stratification (McLeod and Murphy 1977b). During natural stratification, decomposition of the samara is 3 times that resulting from cold-room stratification. Under natural stratification, the samaras were 71% half-decomposed in 150 days compared to the negligible degradation resulting from artificial stratification (McLeod and Murphy 1977b).

Maximum laboratory germination (72%) occurred when temperature fluctuated between 16 and 22 °C; germination of 60% was the best constant temperature (17 °C) value (McLeod and Murphy 1977b). Germination of imbibed seeds exposed to 4 hours daily of 40 °C temperatures was reduced from 45% after 1 week down to 0% after 4 weeks of exposure (McLeod and Murphy 1977b). Germination tests can be made in sand flats at temperatures alternated diurnally from 25 to 10 °C. Germinative capacity in 6 tests ranged from 10 to 91% but averaged only 28% (Brinkman and Schlesinger 1974).

Germination is epigeal (figure 3). In imbibed seeds, it takes 5 to 20 days for the hypocotyl to emerge in the field. Root extension occurred over the 10 weeks following radicle emergence, with 65% completed in 4 weeks and growth about 11 cm long (McLleod and Murphy 1977b).

Nursery practice. Seed should be either fall-sown or stratified over most of the winter and sown in the spring. Seedlots of cultivar 'Aurea' sown immediately after collection germinated 47%; those seeds subjected to 2 to 3 months of cold stratification and then sown germinated 100% (Dirr and Heuser 1987). If seeds are sown in the fall, the seedbeds should be mulched to reduce effects of freezing and thawing. When seeds were buried 4 cm (1 $^1/_2$ in) deep, over two-thirds never emerged from the ground after germination (McLeod and Murphy 1977b). Some of the seedlings have yellow foliage color (Dirr and Heuser 1987). Propagation also is possible by layering, grafting, or budding.

Figure 3—*Ptelea trifoliata*, common hoptree: seedling development at 1, 2, and 10 days after germination.



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Fabaceae—Pea family

Pterocarpus Linn.

padauk, narra

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Growth habit, occurrence, and use. Although there are several *Pterocarpus* species scattered throughout the tropics, only Burma *padauk* (*P. macrocarpus* Kurz) and India *padauk* (*P. indicus* Willd.), also called *narra* or Burmese rosewood, are commonly planted. Both are large trees that produce reasonably long and straight boles in closed stands but develop short boles and spreading crowns when open-grown. Older trees have moderate buttresses and large roots that run along the surface of wet or clayey soil. Both have lush, green foliage and cast a moderately dense shade. Both have naturalized in Puerto Rico but spread very slowly.

Burma padauk is native to upland areas in Myanmar, Thailand, Kampuchea, and Vietnam (Francis 1989). Because of its annual yellow floral display and pleasing foliage and form, this species has become a very popular ornamental and shade tree in Puerto Rico, Florida, and the U.S. Virgin Islands (Francis 1989). It has naturalized in (at least) Puerto Rico (Francis and Liogier 1991). Burma padauk is quite at home in frost-free areas that receive from 1,000 to 2,000 mm of mean annual precipitation.

India padauk is native to the Andaman Islands (India), Malaysia, Indonesia, and the Philippines (Little and Wadsworth 1964). Although it has virtually the same form, foliage, and floral display as the Burma padauk, India padauk requires somewhat higher rainfall (above 1,500 mm/year) (Troup 1921). It has been planted for reforestation in Hawaii (Neal 1965) and in forestry trials in Puerto Rico.

Both species have good forestry potential. They tolerate a wide range of soil types and can be planted in cleared sites or small forest openings. The wood of both species varies from yellow to dark red; the rich colors and figures are highly prized for furniture and decorative uses (Chudnoff 1984). Even the lower grades of wood are useful for posts, ship timbers, and construction because of their resistance to termites and rot (Hundley 1956; Rendle 1970).

Flowering and fruiting. The sweet-scented flowers are produced copiously in panicles and racemes. Individual flowers are about 1.6 cm across. They are pollinated by honey bees (*Apis mellifera* L.) and other insects. Fruits mature about 6 months after flowering and fall off the tree gradually over several months. Padauk fruits are lenticular-shaped legumes with a flat wing that circles its edge (figure 1). The straw-colored to light brown legumes of India padauk are generally 3 to 4 cm across and the light brown legumes of Burma padauk measure 4.5 to 7.5 cm across (Little and Wadsworth 1964; Little and others 1974). However, considerable variation in size occurs between the legumes of individual trees and tress from various sources within both species. Legume production usually begins in open-grown trees between 5 and 10 years of age. Large trees produce about 35 liters (1 bu) or more of legumes annually.

Collection, cleaning, and storage. At maturity, the legumes dry and turn from greenish yellow to straw colored or light brown. Seed-bearing branches can be clipped with pruning poles if the need for legumes is urgent. Because the legumes and their seeds do not deteriorate for several months after falling, it is more efficient to wait until most of the crop has fallen and pick up the legumes from the ground. A sample of air-dried legumes of Burma padauk grown in Puerto Rico yielded 1,067 legumes/kg (485/lb) (Francis 1989). The legumes of India padauk (source unknown) were reported to yield 1,200 to 1,300 legumes/kg (545 to 590/lb) (MacDicken and Brewbaker 1984). The seeds of padauk are fragile (figure 2) and the legumes are tough, making extraction impossible mechanically and difficult by hand. A sample of legumes of Burma padauk from Puerto Rico yielded an average of 2.6 seeds/legume (Francis 1989); shelled seeds averaged 11,500/kg (5,200/lb) (Francis and Rodríguez 1993). Padauk seeds are normally stored and planted in the legumes. Air-dried seeds in their legumes will still germinate after 1 year of storage in plastic bags at room temperature. The effect of refrigeration is unknown but probably beneficial.

Figure 1—*Pterocarpus macrocarpus*, Burma padauk: legumes and seeds (**top right**).

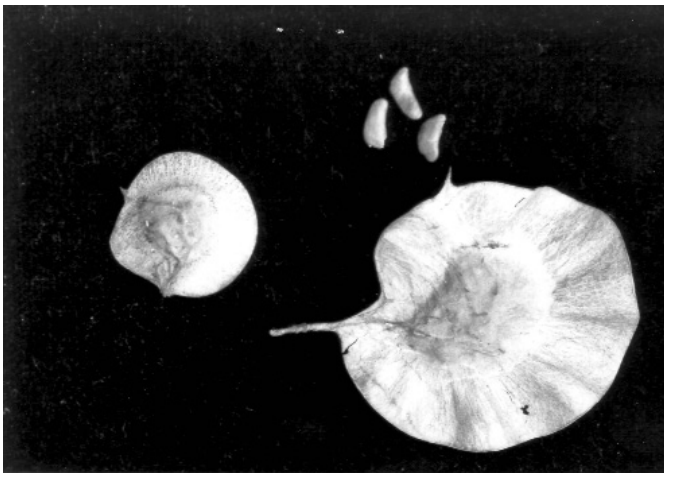


Figure 2—*Pterocarpus macrocarpus*, Burma padauk: longitudinal sections of seeds.

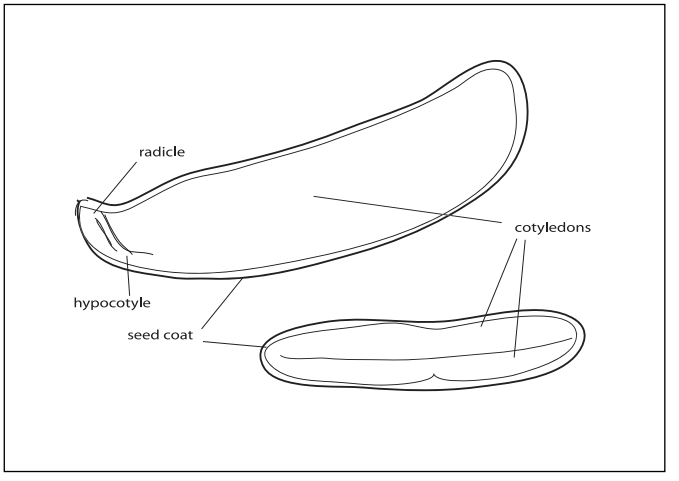
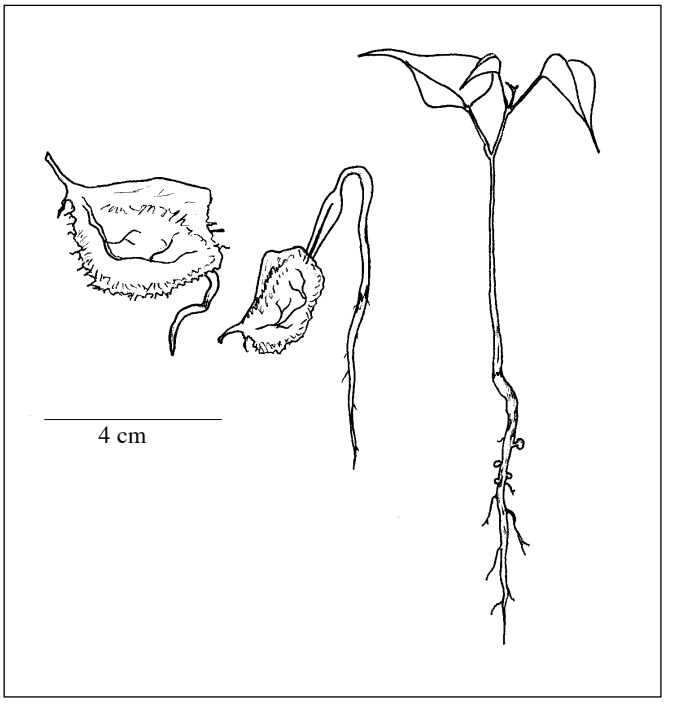


Figure 3—*Pterocarpus macrocarpus*, Burma padauk: germinating seed showing seedling development.



Germination. The first seeds germinate within and begin to grow through the legumes about 1 to 2 weeks after planting. The remaining seeds continue germinating for several weeks thereafter. Often 2 or 3 seedlings emerge from each legume. Germination is epigeal (figure 3). In a comparison of the germination of shelled seeds to seeds within legumes in Puerto Rico, shelled seeds germinated in 5 days and gave 70% germination within 2 weeks. Unshelled legumes did not begin germination for 11 days and only 64 seedlings/100 legumes emerged within 2 months. However, effective yield was only about two-thirds this amount because about half the seedlings occurred in multiples and only 1 germinant/legume can produce a plantable seedling. In Burma, shelled seeds gave 80 to 90% germination. Moreover, seeds from 1-year-old legumes collected from the ground germinated better than new seeds collected from the tree (Hundley 1956). Seeds from Burma padauk germinated well (around 80% over a wide temperature range; the best temperature regime seemed to be about 30 °C day and 25 °C night (Liengsiri and Hellum 1988).

Nursery practice. The use of shelled seeds would be recommended, except that they are so difficult to extract. The use of seeds in the legumes requires thinning the plants soon after germination to remove multiples. When true leaves have developed, seedlings are transplanted from the germination bed to bags filled with a potting mixture. After growing under light shade for a few months, the seedlings reach about 0.5 m (1.6 ft) in height and are ready for outplanting (Francis 1989). In Burma, seedlings in plantations grow to 0.6 to 1.2 m (2 to 4 ft) the first year and 1.2 to 2.1 m (4 to 7 ft) the second (Hundley 1956). Thirty planted trees in a small forest plantation in Puerto Rico (situated on clay soil over porous limestone) averaged 1.3 m tall at 14 months after outplanting (Francis 1989). Seedlings intended for ornamental use are often grown in 12- to 20-liter (3- to 5-gal-size) plastic pots until they reach 2 to 3 m (6.5 to 7.5 ft) in height before outplanting. In the Philippines, branch cuttings of India padauk about 8 cm (3 in) in diameter are rooted after hormone treatment to produce "instant trees" (Dalmacio and others 1978).

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Rosaceae—Rose family

Purshia DC. ex Poir.

bitterbrush, cliffrose

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Growth habit, occurrence, and use. The bitterbrush genus—*Purshia*—as presently circumscribed comprises 8 species of decumbent to arborescent shrubs of interior western North America. Three are common in the United States (table 1). The type species—antelope bitterbrush—has an essentially northern distribution, whereas cliffrose has an essentially southern distribution, and desert bitterbrush occurs in parts of the geographic area where the other 2 species have overlapping distributions. Cliffrose, along with the 5 Mexican species of the genus, has been traditionally referred to the genus *Cowania* D. Don. Cliffrose regularly forms hybrids with antelope bitterbrush, and desert bitterbrush could be interpreted as a stabilized hybrid between these species (Stutz and Thomas 1964). In fact, molecular genetics work by Jabbes (2000) indicates that *Purshia* was derived from *Cowania*. We follow Welsh and others (1987) in treating the group as congeneric under the name *Purshia*.

Members of the genus are erect, spreading or decumbent, freely branched shrubs up to 6 m in height. They have small, alternate, simple, apically lobed leaves that may be evergreen (cliffrose) to winter deciduous (antelope bitterbrush). Layering forms of bitterbrush (principally antelope bitterbrush) may resprout after fire, but erect forms are usually not fire tolerant. Because of their interesting habits, attractive foliage, and showy flowers, bitterbrush species have potential as ornamentals in low-maintenance landscapes.

Bitterbrush species are hardy and drought tolerant. Antelope bitterbrush occurs mainly on well-drained soils over a wide elevational range and is often a principal component of mixed shrub, pinyon–juniper, ponderosa pine, and sometimes lodgepole pine communities, where it is notable as a nurse plant for conifer seedlings (Geier-Hayes 1987; McArthur and others 1983; Nord 1965; Tew 1983). It is valued as a high-protein browse for domestic and wild ungulates, being especially important on winter ranges (Bishop and others 2001; Scholten 1983). It also supplies high-quality forage during spring and summer months (Austin and Urness 1983; Ngugi and others 1992). Cliffrose grows primarily on rocky sites in blackbrush–joshua tree woodland, sagebrush–grassland, piñyon–juniper woodland, mountain brush, and ponderosa pine communities, sometimes forming extensive stands on south-facing ridge slopes (McArthur and others 1983). It is also an important browse species, especially for mule deer (*Odocoileus hemionus*) (Plummer and others 1968). Desert bitterbrush is a component of blackbrush, chaparral, and piñyon–juniper communities.

The bitterbrush species form actinorhizal root nodules that fix nitrogen when soil water is adequate (Bond 1976;

Table 1—*Purshia,* bitterbrush, cliffrose: common names and geographic distributions

Scientific name & synonym(s)	Common name	Geographic distribution
***P. glandulosa* Curran** *P. tridentata* var. *glandulosa* (Curran) M.E. Jones	**desert bitterbrush**	SW Utah, S Nevada, & S California
***P. mexicana* (D. Don) Henrickson** *Cowania mexicana* D. Don	**cliffrose**	S Colorado W through Utah to S California & S to New Mexico, Arizona, Sonora, & Chihuahua
***P. tridentata* (Pursh) DC.**	**antelope bitterbrush**	British Columbia to W Montana, S to New Mexico, California, & N Arizona

Sources: Little (1979), Sargent (1965), Vines (1960).

Kyle and Righetti 1996; Nelson 1983; Righetti and others 1983). They readily function as pioneer species that colonize harsh, steep disturbances and have been used extensively in revegetation and disturbed-land reclamation. An ethanol extract of antelope bitterbrush aerial stems was found to inhibit reverse transcriptase of HIV-1 and to contain the cyanoglucosides pushianin and menisdaurin (Nakanishi and others 1994). Unfortunately, the cyanoglucosides lacked the inhibitory activity of the original extract. Cliffrose has also been examined for beneficial secondary products (Hideyuki and others 1995; Ito and others 1999). Specific populations of antelope bitterbrush with distinctive attributes are recognized and are commercially harvested and sold, although to date only two ('Lassen' and 'Maybell') have been formally named (Davis and others 2002; Shaw and Monsen 1995).

Flowering and fruiting. Most of the medium to large, perfect, cream to sulfur yellow flowers of this genus appear during the first flush of flowering in April, May, or June, depending on elevation. In areas where they co-occur, antelope bitterbrush usually flowers 2 to 3 weeks before cliffrose. The flowers are borne on lateral spurs of the previous year's wood (Shaw and Monsen 1983). In cliffrose, summer rains may induce later flowering on current-year leaders, but these flowers rarely set good seeds (Alexander and others 1974). The flowers have a sweet fragrance and are primarily insect-pollinated. Each has 5 sepals, 5 separate petals, numerous stamens, and 1 to 10 pistils borne within a hypanthium. Flowers of antelope and desert bitterbrushes usually contain a single pistil with a relatively short, non-plumose style, whereas those of cliffrose contain multiple pistils. The pistils develop into single-seeded achenes with papery pericarps. In cliffrose the achenes are tipped with persistent) plumose styles, 22 to 50 mm (1 to 2 in) in length, that give the plants a feathery appearance in fruit.

The main fruit crop ripens from June through August, depending on species and elevation. Plants begin to bear seeds as early as 5 years of age. At least some fruits are produced in most years, and abundant seedcrops are produced on average every 2 to 3 years (Alexander and others 1974; Deitschman and others 1974). Cliffrose seeds (figure 1) are apparently dispersed principally by wind (Alexander and others 1974). Scatter-hoarding rodents such as chipmunks (*Tamias* spp.), disperse bitterbrush seeds (figure 2) and seedlings from rodent caches appear to account for nearly all (99%) natural recruitment as survivors from seedling clumps containing 2 to >100 individuals (Evans and others 1983; Vander Wall 1994).

Seed collection, cleaning, and storage. Bitterbrush plants produce more leader growth in favorable water years,

Figure 1—*Purshia*, mexicana, cliffrose: achenes:

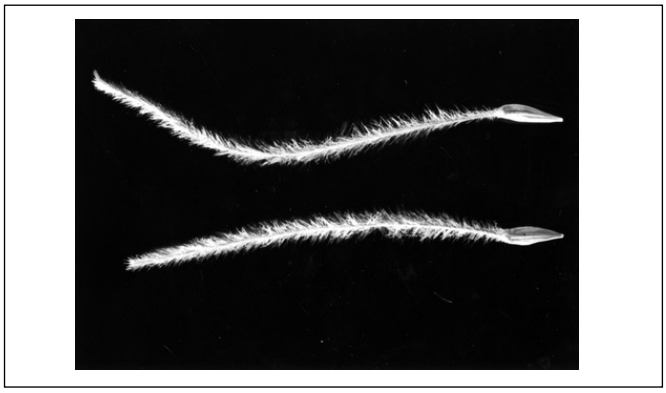
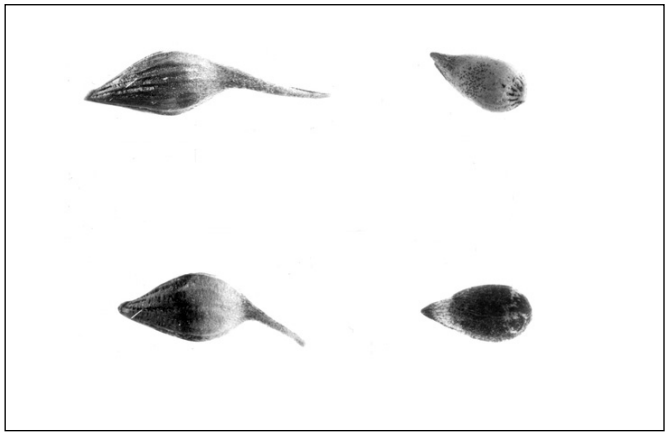


Figure 2—*Purshia*, bitterbrush: achenes (**left**) and cleaned seeds (**right**) of *P. glandulosa*, desert bitterbrush (**top**) and



and leader length is an indicator of the potential for seed production the following year (McCarty and Price 1942; Young and Young 1986). Fruits may be hand-stripped or beaten into hoppers or other containers when fully ripe; harvesters should take care to protect themselves from the fiberglass-like style hairs in the case of cliffrose. The window of opportunity is quite narrow, as ripe fruits are easily detached by wind and do not persist long on the plant, making close monitoring during ripening advisable. Plants in draws and other areas protected from wind may retain their seeds longer. Maturation dates for antelope bitterbrush have been predicted with reasonable accuracy using elevational and latitudinal predictors (Nord 1965). Well-timed harvests of antelope bitterbrush average 168 to 224 kg/ha (150 to 200 lb/acre) but may range up to 560 kg/ha (500 lb/acre) (Nord 1965). Fill percentages are usually high, although insects or drought stress during filling can damage the crop (Shaw and Monsen 1983). Krannitz (1997a) reported the variation in seed weight from 240 bitterbrush plants representing 10 sites in the southern Okanagan Valley of Canada varied from

5 to 46 mg/seed with the population being skewed toward the small seeds. The representative weights given in table 2 are of cleaned seeds (the smaller fraction is removed in cleaning). Krannitz also found that larger seeds had greater concentrations of nitrogen than smaller seeds and that shrubs that had been browsed most intensively the winter before seed-set had seeds with greater concentrations of magnesium (Krannitz 1997b).

A seed cleaner or barley de-bearder may be used to break the styles from cliffrose achenes and to remove the papery pericarps of bitterbrush species. The achenes (cliffrose) or seeds (bitterbrush species) may be separated from the inert material—which usually comprises from one-third (antelope bitterbrush) to two-thirds (cliffrose) of the total weight—using a fanning mill (Alexander and others 1974; Giunta and others 1978). In cliffrose, the achene is considered the seed unit, as the seed is held tightly within the pericarp and cannot be threshed out without damage. In bitterbrush species, the seeds are easily threshed free of their papery pericarps, and the seed unit is the seed itself. If properly dried (<10% moisture content), seeds of bitterbrush species can be warehouse-stored for 5 to 7 years (Belcher 1985) or even up to 15 years without losing viability (Stevens and others 1981).

Germination and seed testing. Bitterbrush and cliffrose seeds are mostly dormant but the inhibiting mechanism(s) is not understood (Booth 1999; Booth and Sowa 2001; Dreyer and Trousdale 1978; Meyer 1989; Meyer and Monsen 1989; Young and Evans 1976, 1981). Moist chilling is preferred for breaking dormancy (table 3). Although some collections are less dormant than others are—as indicated by germination percentages for untreated or partially treated seeds (table 3) (Booth 1999; Meyer and Monsen 1989)—there is no obvious relationship between collection site and chilling requirement (Meyer and Monsen 1989). Dormancy might be affected by high seed temperature (30 °C) while in the dry state (Meyer 1989) and is certainly affected by imbibition temperature (Booth 1999; Meyer 1989).

Young and Evans (1981) reported the required chilling period was shorter at 5 °C, than at 2 °C for all 3 species, and that adequately chilled seeds could germinate over a wide range of temperatures. A 28- to 30-day chill at 1 to 3 °C is highly recommended (AOSA 1993; Belcher 1985; Booth 1999; Meyer 1989) followed by post-chill incubation at 15 °C (10/20 °C for cliffrose). Desert bitterbrush needs only 14 days of chilling (Belcher 1985). Germination of antelope bitterbrush seeds can be facilitated by 24 hours of soaking in cold (2 °C) water prior to moist chilling, but soaking in

Table 2—*Purshia,* bitterbrush and cliffrose: seed yield data (seeds/weight) for mechanically cleaned seeds*

Species	Mean /kg	Mean /lb	Range /kg	Range /lb
P. glandulosa	50,850	26,540	45,000–90,000	20,300–40,900
P. mexicana	129,000	58,600	108,000–210,000	49,000–95,000
P. tridentata	35,000	15,750	29,000–51,000	13,400–23,200

Sources: Alexander and others (1974), Belcher (1985), Deitschman and others (1974), Meyer (2002), Meyer and others (1988).

Table 3—*Purshia,* bitterbrush and cliffrose: germination data

Species	Mean percentage of initially viable seeds: 0	2 wk	4 wk	6 wk	8 wk	10 wk	12 wk	Samples
P. glandulosa	—	—	—	93	—	—	100	1*
	10	56	81	100	65	—	32	1†
P. mexicana	6	33	83	94	100	—	—	6
	6	64	91	100	32	—	19	1†
P. tridentata	2	43	88	98	100	—	—	13
	13	60	100	100	36	—	37	1†

Sources: Deitschman and others (1974), Meyer (2002), Meyer and Monsen (1989), Young and Evans (1981).
Note: Values are expressed as percentage of initially viable seeds after moist chilling at to 2 °C for 0 to 12 weeks followed by incubation at 15 °C or 10/20 °C for 4 weeks.
* These seeds were chilled at 3 to 5 °C and germination was scored during chilling.
† Decrease in germination percentage after 6 weeks was due to seed mortality during the test.

warm water (>10 °C), or holding imbibed seeds at warm temperatures, decreases seedling vigor and increases pregermination seed-weight loss (Booth 1999; Booth and Sowa 2001). Longer, colder chilling periods (28 days, 2 °C vs 14 days, 5 °C) increases seedling vigor (Booth 1999; Booth and Morgan 1993). Recommended germination test periods are 28 days for antelope bitterbrush and cliffrose (AOSA 1993).

Soaking seeds in hydrogen peroxide (Everett and Meeuwig 1975) or a 1 to 3% solution of thiourea (Pearson 1957; Young and Evans 1981) will induce germination but these methods have not proven useful for field plantings. Booth (1999) found thiourea-treated seeds to have the lowest seedling vigor among 8 dormancy-breaking treatments and attributed the lower vigor to residual dormancy and to weight loss resulting from accelerated respiration (Booth 1999; Booth and Sowa 2001).

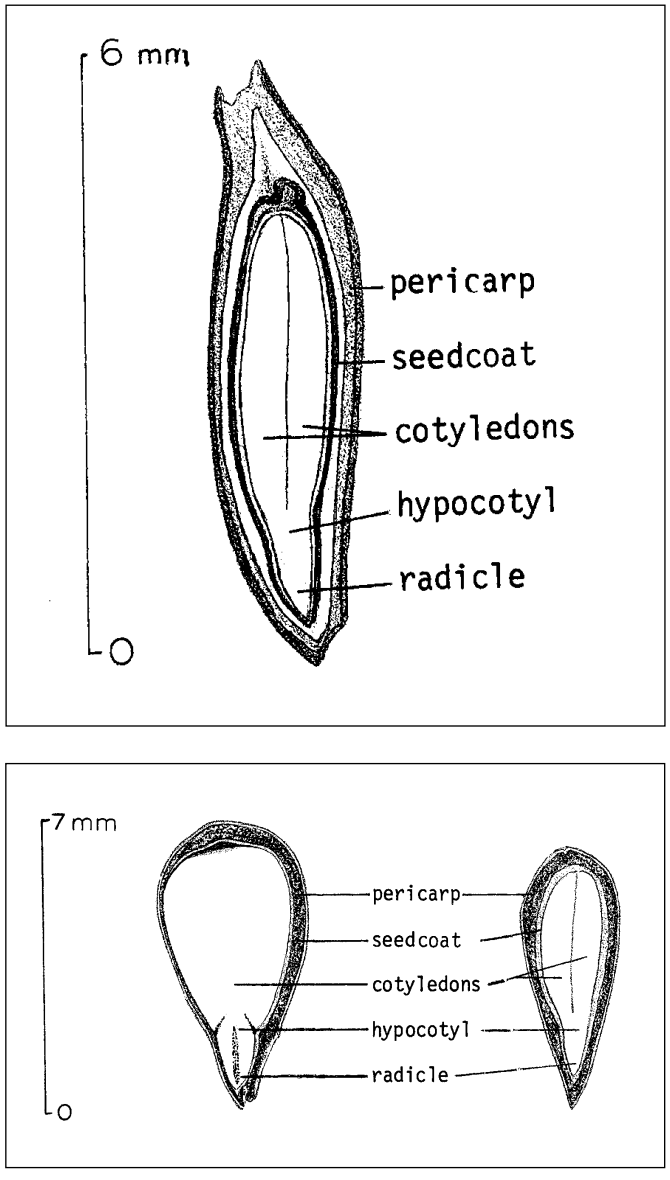
Tetrazolium (TZ) staining is acceptable for evaluating seed quality of bitterbrush (AOSA 1993; Weber and Weisner 1980). Meyer (2002) found no significant difference between TZ viability estimates and germination perentages after 8 weeks of chilling for either cliffrose or antelope bitterbrush. For TZ viability testing, seeds should be clipped at the cotyledon end (figure 3) and soaked in water for 6 to 24 hours. Then, the embryos can be popped-out of the cut end by gentle finger pressure and immersed in 1% TZ solution for 4 to 12 hours at room temperature before evaluation. Cliffrose must be soaked longer than bitterbrush before the embryos can be popped out.

Field seeding and nursery practice. Bitterbrush species are generally sown in fall or early winter in a mixture with other shrubs and forbs. They are used in upper sagebrush, piñyon-juniper woodlands, and mountain brush vegetation types to improve degraded wildlife habitat or revegetate bare roadcuts, gullies, south slopes, and other difficult sites (Alexander and others 1974). Because of the chilling requirement, spring-seeding should be avoided. Seeds may be drilled at a depth of 6 to 12 mm ($^1/_4$ to $^1/_2$ in) or deeper. Deeper seeding may provide some protection from rodent depredation, which can be a serious problem (Alexander and others 1974; Evans and others 1983; Vander Wall 1994). Seeding in late fall or early winter, when rodents are less active, may also alleviate this problem.

Broadcast-seeding is generally unsuccessful unless provision is made for covering the seeds. Aerial seeding is not recommended. The seedlings do not compete well with weedy annual grasses such as red brome (*Bromus rubens* L.) and cheatgrass (*B. tectorum* L.), or with heavy stands of perennial grasses. They are sensitive to frost and drought during establishment (Plummer and others 1968). Recommended (drill) seeding rates for cliffrose are 5 to 10% of the shrub mix at 8 to 10 kg/ha (7 to 9 lb/ac) (Alexander and others 1974; Plummer and others 1968) and 16 to 65 seeds/m (5 to 20 seeds/ft) for bitterbrush. The higher rates are advisable for both species when seeding in crust-forming soils. The most effective method of seeding large areas in conjunction with chaining is with a seed dribbler that drops seeds in front of the bulldozers pulling the chain.

Hand-planting into scalped sites with a tool such as a cased-hole punch planter can be very effective on a small scale (Booth 1995). The purpose of scalping is to control herbaceous competition within a half-meter ($1\ ^1/_2$-ft) radius of the planting spots. Treating seeds with fungicide, planting seeds in groups, and planting with vermiculite to aid in moisture retention have all improved emergence and establishment of antelope bitterbrush (Booth 1980; Evans and

Figure 3—*Purshia*: longitudinal section of *P. mexicana*, cliffrose (**top**) and *P. tridentata*, antelope bitterbrush (**bottom**).



others 1983; Ferguson and Basile 1967). Good emergence depends on adequate snowcover (Young and others 1993).

Bitterbrush species are readily grown as bareroot or container stock, and outplanting may succeed where direct seeding has failed (Alexander and others 1974). Care must be taken to lift or transplant stock only when the plants are hardened or dormant, as survival of actively growing plants is generally low (Landis and Simonich 1984; Shaw 1984). Plants are easier to handle and have higher survival rates if allowed to reach sufficient size before field transplanting. One-year-old bareroot stock or container seedlings 16 to 20 weeks of age are usually large enough (Alexander and others 1974; Shaw 1984). On more level terrain, a conventional tree-planter may be used (Alexander and others 1974). Transplanting should be carried out at a time and in such a way as to assure that the transplants will have adequate moisture for root development for 4 to 6 weeks after planting. This may be accomplished by planting in very early spring or by watering at the time of planting. Fall-planted seedlings may require supplemental watering. Controlling competition from weedy annual or perennial grasses before planting will enhance survival and first-season growth.

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Rosaceae—Rose family

Pyrus L.

pear

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Growth habit, occurrence, and use. The pear genus—*Pyrus*—probably originated in the mountain regions of what is now western and southwestern China and evolved and spread eastward and westward. Throughout the world, 24 primary species are presently recognized (table 1). Pear species are not native to North or South America (Rehder 1986), although some species have naturalized here.

The common pear (*P. communis*), which is cultivated for its fruit, probably originated from complex hybridization of wild progenitors, the wild European pear, *P. korschinskyi* (synonym = *P. pyraster*), and *P. communis* var. *caucasica* in the region of the Caucasus Mountains (Westwood 2002). Fruits of the common pear are pyriform, although the fruits of its progenitors tend to be round. The astringent fruits of the snow pear and hybrids between the common pear and the snow pear have been used in Western Europe to produce the fermented cider-like beverage called "perry."

Pears have been cultivated in Asia for at least 3,000 years (Kikuchi 1946). The fruits of many pears cultivated in Asia tend to be round. Lombard and Westwood (1987) consider that the (Japanese or Chinese) sand pear was the first pear species domesticated for its edible fruit. The Ussuri pear, the other predominant Asian species, has small, round astringent fruits. Natural hybridization between these 2 wild species occurred in central China and selection for large fruited, edible types has been occurring for several thousand years.

Most modern Japanese and Korean pear cultivars are derived from the sand pear. The principle commercial pears in China are derived from 3 species—sand and Ussuri pears and the hybrid species *P.* × *bretschneideri,* which is also known as the "Chinese white pear" (Lombard and Westwood 1987; Teng and others 2002). Recent analysis of pear species using DNA markers such as simple sequence repeats (SSR) suggest that the Chinese white pear is closely related to both sand and Ussuri pears (Yamamoto and others 2002) and might be considered as a subspecies of sand pear (Teng and others 2002).

Several Asian species have fruits with the size and shape of a pea. The Japanese and Korean pea pears and the evergreen pear are considered by some to be varieties or subspecies of Callery pear (Rehder 1986; Yu 1979). The birchleaf pear has the smallest sized fruit of the pea pears.

The common pear has naturalized in the United States (Gill and Pogge 1974). The Ussuri pear, introduced from Asia about 1855, has been grown on the northern Great Plains in shelterbelt and environmental plantings and in New England. It has contributed genes for cold-hardiness and resistance to fire blight in pear breeding programs (Stushnoff and Garley 1982). Other traits inherent in this species include vigor, dense growth, attractive glossy foliage, and scarlet autumn leaf color. Pear cultivars adapted to warm winter areas have been derived from the Pashia pear of central Asia. The pendulous form of the willow-leaf pear makes it a unique ornamental landscape plant. Flowering ornamental selections of the Callery pear and the evergreen pear are widely planted as street trees in the United States. The use of the evergreen pear is limited to warm-winter areas such as California and the more southerly states. These species are often referred to as "flowering pears" in the urban landscape. The Callery pear has become naturalized in the eastern United States and is now considered a weed in some areas such as the Maryland suburbs of Washington, DC.

Pears are deciduous, rarely evergreen, sometimes thorny trees or shrubs. Their leaves are serrate, crenate, or entire; rarely lobed. The petioles are stipulate and the buds are involute, with imbricate scales.

Flowering and fruiting. Pear species are cross-compatible sexual diploids (x = 17). Individual genotypes are generally self-incompatible. The perfect flowers bloom on 2-year or older spurs, between March and April in the Northern Hemisphere and appear before or with the new leaves (table 2). The inflorescence consists of 6 to 8 flowers occurring in umbel-like racemes. Petals are white, or rarely pinkish with reflexed or spreading sepals, 20 to 30 pink, red,

Table 1— *Pyrus,* pear: nomenclature, growth habit, and occurrence

Scientific name & synonym(s)	Common name(s)	Growth habit	Range & extensions
***P. amygdaliformis* Vill.** *P. sinaica* Dom.-Cours.	**almond-leaf pear**	Shrub to small tree, 1–2 m	Mediterranean Europe & Asia Minor
***P. betulifolia* Bunge**	**birch-leaf pear**	Large tree, 5–6 m	Central & N China
***P. calleryana* Decne.**	**Callery pear,** pea pear, Chinese pea pear	Medium tree, 3–5 m	Central & S China
***P. communis* L.** *P. asiae-mediae* Popov; *P. balansae* Decne *P. boissieriana* Buhse; *P. elata* Rubtzov *P. medvendevii* Rubtzov	**common pear,** European pear, cultivated pear	Large broad pyramidal tree, 5–6 m	W to SE Europe, Turkey; in world-wide cultivation
***P. communis* ssp. caucasica (Fed.) Browicz** *P. caucasica* Fed.	**Caucasus pear**	Large tree, 5–6 m	SE Europe, Greece
***P. cordata* Desv.**	**heart-leaf pear,** Plymouth pear	Shrub to small tree, 2–3 m	SW England, W France, Spain, & Portugal
***P. cossonii* Rehder** *P. longipes* Coss, S. Dur.	**Algerian pear**	Medium tree, 3–4 m	Algeria
***P. dimorphophylla* Makino** *P. calleryana* var. *dimorphophylla* (Makino) Koidz	**Japanese pea pear**	Medium tree, 3–4 m	Japan
***P. elaeagrifolia* Pall.** *P. kotschyana* Boiss ex Deone	**elaeagnus-leaf pear**	Medium tree, 3–4 m	SE Europe, Russia, & Turkey
***P. fauriei* C.K. Schneid.** *P. calleryana* var. *fauriei* (Schneid.) Rehd.	**Korean pea pear**	Shrub to small tree, 1–2 m	Korea
***P. gharbiana* Trab.**	—	Small tree, 1–2 m	Morocco & W Algeria
***P. glabra* Boiss.**	—	Medium tree, 3–4 m	Iran
***P. koehnii* C.K. Schneid**	**evergreen pear**	Small to medium tree, 1–3 m	Taiwan & SE China
***P. korshinskyi* Litv.** *P. pyraster* Burgsd. *P. communis* var. pyraster	**wild European pear**	Tree to 15 m	Afghanistan; W Russia; Central Asia
***P. mamorensis* Trab.**	**Mamor Mountain pear**	Small tree	Morocco
***P. nivalis* Jacq.**	**snow pear,** perry pear	Thornless medium tree, 3–4 m	W Central & S Europe
***P. pashia* Buch.-Ham. ex D.Don** *P. kumaoni* Decne *P. varoilosa* Wall ex G. Don. *P. wilhelmii* C. Schneid.	**Pashia pear,** India wild pear	Medium tree, 3–4 m	Pakistan, India, & Nepal
***P. pseudopashia* T.T. Yu**	**Kansu pear**	Tree	NW China (Yunnan & Guizhou)
***P. pyrifolia* (Burm.f.) Nakai** *P. serotina* Rehd.	**sand pear,** Japanese pear, Chinese pear	Medium to large tree, 3–5 m	China, Japan, Korea, & Taiwan
***P. regelii* Rehder** *P. heterophylla* Regel G.Schmalh	**Regel pear**	Shrub or tree to 1–2 m	S central Asia & Afghanistan
***P. salicifolia* Pall.**	**willow-leaf pear**	Small tree, 1–2 m	NW Iran, Armenia, Turkey, & S Russia
***P. syriaca* Boiss.**	**Syrian pear**	Small tree, 1–2 m	Middle East, SW Russia
***P. ussuriensis* Maxim.;** *P. lindleyi Rehd.* *P. ovoidea* Rehd. *P. sinensis* Lindley	**Ussuri[an] pear,** Harbin pear, Manchurian pear	Small to medium tree, 1–3 m	Siberia, N China, Korea, Mongolia
***P. xerophylla* T.T. Yu**	—	Tree	N China

Sources: LHBH (1976), Bell (1991), Hedrick (1921), Lombard and Westwood (1987), Rehder (1986).

Table 2—*Pyrus,* pear: flowering and fruiting dates*

Species	Bloom season†	Ripening season‡
P. amygdaliformis	M–ML	L
P. betulifolia	M–ML–L	L
P. calleryana	E–EM–M	L
P. communis (wild types)	EM–M–ML	EM–M–ML–L
P. communis (cultivars)	E–EM–M–ML–L	E–EM–M–ML–L
P. cordata	M–ML–L	ML–L
P. cossonii	M–ML–L	M–ML–L
P. dimorphophylla	E–M–ML	L
P. elaeagrifolia	EM–M–ML	ML
P. fauriei	EM–M–ML	ML–L
P. gharbiana	ML	ML
P. glabra	EM	M–ML
P. hondoensis	EM–M–ML	M–ML–L
P. koehnei	E–EM–M–ML	L
P. korshinskyi	EM–M–ML	EM–M–ML–L
P. mamorensis	ML	L
P. nivalis	ML	ML–L
P. pashia	E–EM–M–ML–L	L
P. pyrifolia (wild types)	EM–M	M–ML–L
P. pyrifolia (cultivars)	EM–M–ML	EM–M–ML–L
P. regelii	M–ML	ML
P. salicifolia	EM–M–ML	ML–L
P. syriaca	EM–M	ML–L
P. ussuriensis (wild types)	E–EM	EM–M–M– L
P. ussuriensis (cultivars)	E–EM–M	M–ML–L

* Observations made at the USDA ARS National Clonal Germplasm Repository in Corvallis, OR, 1988 through 1994.
† Average full bloom: E = March 13–March 23, EM = March 24–April 2, M = April 3–April 7, ML = April 8–April 17, L = April 18–April 26.
‡ Average fruit ripening: E = before July 6, EM = July 6–August 8, M = August 9–August 25, ML = August 26–September 28, L = after September 28.

or purple anthers, 2 to 5 free styles that are closely constricted at the base, and 2 ovules per locule.

The fruit is a globose or pyriform pome with persistent or deciduous calyx. Most Asian species, with the exception of the Ussuri pear, have deciduous calyxes. The fruit of different species ranges from about 0.5 to 20 cm in length and are quite diverse (figure 1). The extracarpellary tissue, which comprises the bulk of the fruit flesh, may contain sclerenchyma, that is, stone cells. The ground-color of the fruit skin may change from green to yellow or red during maturation, and russeted lenticels may be prominent on some species. Environmental conditions, such as humidity, may cause russetting or browning of the maturing skin. The ripening season for cultivated pears in the Northern Hemisphere ranges from June through December (table 2). Fruit from some species can be eaten directly from the tree, whereas others may require a period of cold storage to ripen or soften the fruit before it can be eaten. Common pears growing wild in Russia are reported to be biennial producers (Al'benskii and Nikitin 1956).

Collection of fruits; extraction and storage of seeds. The mature fruits can be picked from trees or some can be shaken to the ground. Seeds (figure 2) can be recovered by macerating the fruit, drying the pulp, and using a screen to extract the seeds. Small quantities of seeds can also be effectively removed by carefully transversely cutting fruit to expose the locules. Water can also be used to float immature seeds, flesh, and skin away from viable seeds, which sink. Each ripe fruit contains up to 10 smooth black (or nearly black) seeds, each with a thin layer of endosperm (Gill and Pogge 1974). The seeds can then be air-dried. Pear seed characteristics differ greatly by species (figure 3). The small-seeded species—*P. gharbiana,* from N. Africa, and the birch-leaf pear—contain more than 88,000 seeds/kg (40,000/lb). The largest seeded species—Regel, Syrian, and Mamor Mountain pears—contain 11,000 or fewer seeds/kg (5,000 or fewer/lb). The domesticated species contain about 22,000 to 26,000 seeds/kg (10,000 to 12,000/lb) (table 3). Pears are outcrossing species, so seedlings will not be identical to parental genotypes.

Figure 1—*Pyrus,* pear: fruit and seed of *P. ussuriensis*, Ussuri pear (**left**); seeds of *P. calleryana*, Callery pear (**right**).

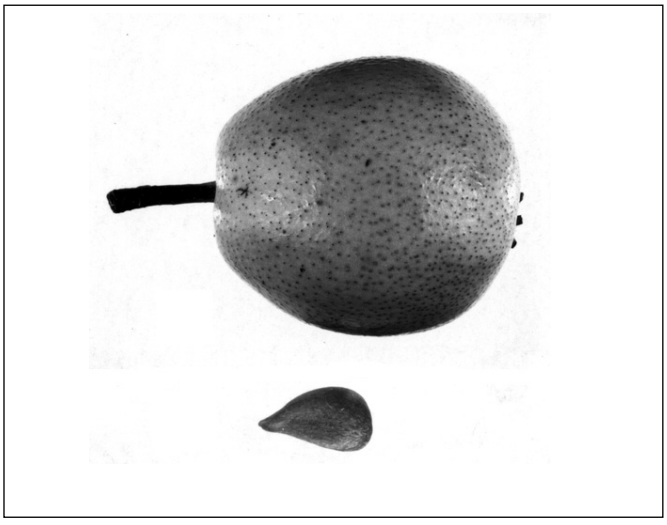
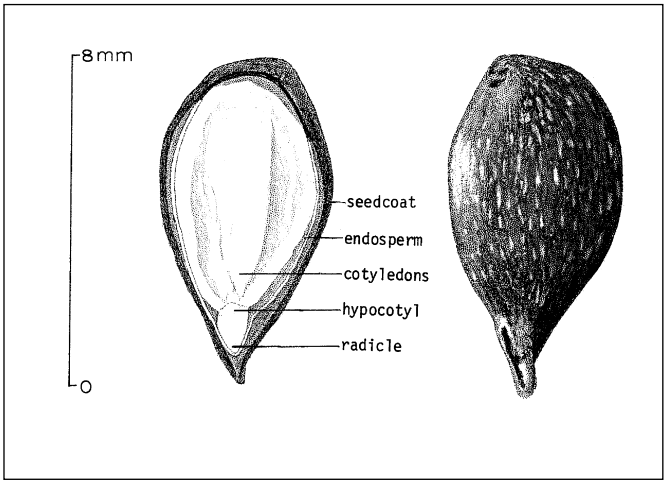


Figure 2—*Pyrus communis* L., common pear: longitudinal section through a seed.



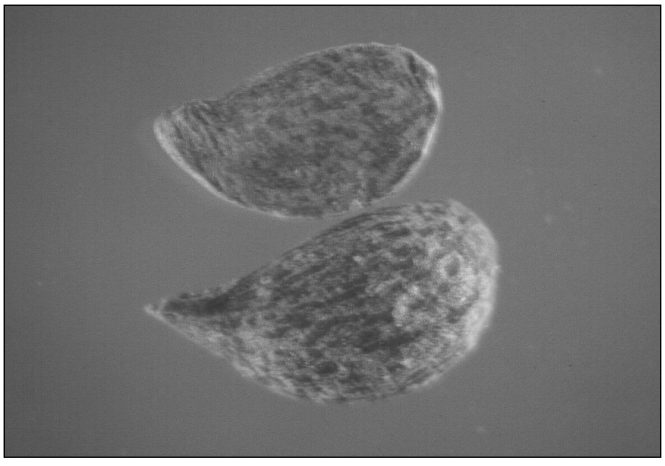
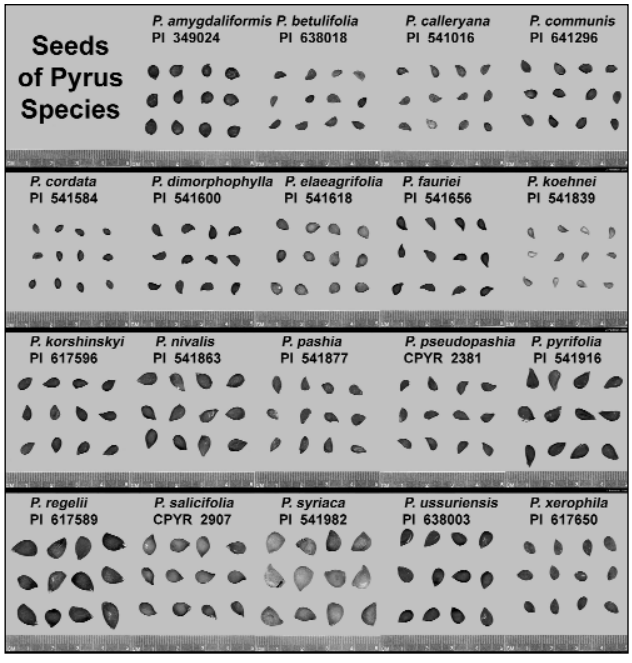


Figure 3—*Pyrus*, pear: seeds of *P. cossonii*, Algerian pear (X); *P. amygdaliformis*, almond-leaf pear (X); *P. betulifolia*, birch-leaf pear (X); *P. calleryana*, Callery pear (X); *P. communis*, common pear (X); *P. cordata,* heart-leaf pear (X); *P. dimorphophylla*, Japanese pea pear (X); *P. elaeagrifolia*, elaeagnus-leaf pear (X); *P. fauriei*, Korean pea pear (X); *P. gharbiana* (X); P. koehnii, evergreen pear (X); *P. korshinskyi* wild European pear (X); *P. mamorensis*, Mamor Mountain pear (X); *P. nivalis,* snow pear (X); *P. pashia*, Pashia pear (X); *P. pseudopashia*, Kansu pear (X); *P. pyrifolia*, sand pear (X); *P. regelii*, Regel pear (X); *P. salicifolia*, willow-leaf pear (X); *P. syriaca*, Syrian pear (X); *P. ussuriensis*, Ussuri pear (X); *P. xerophylla* (X).



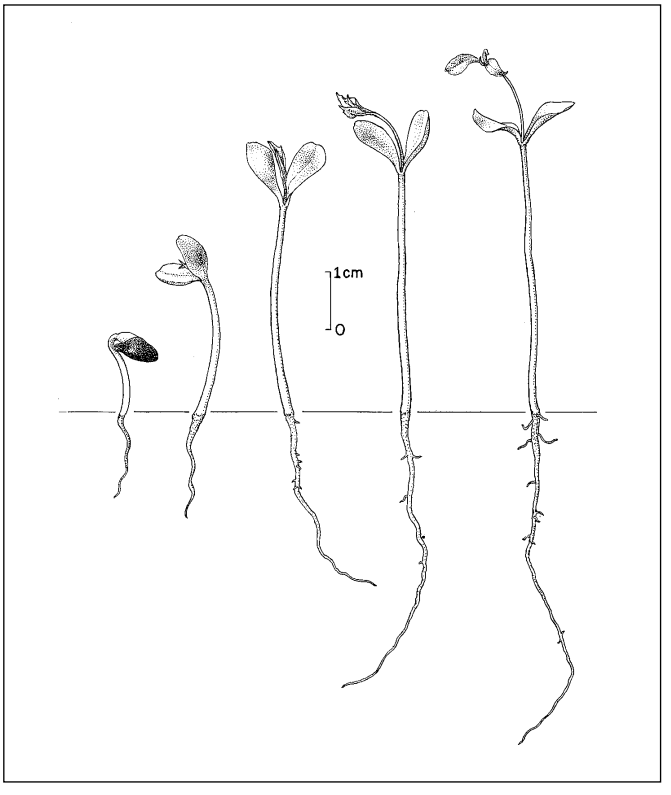
Germination. Seeds of pears extracted from fresh mature fruit in the fall or winter have dormant embryos that require stratification. Species differ in their stratification requirements (table 3). Seed preparation for germination includes a thorough washing and 1 day of water soaking prior to stratification. Seeds must be stratified for 60 to 100 days at about 4 °C. Germination is epigeal (figure 4) and may require from 5 to 30 days at 20 °C (Ellis and others 1985; Macdonald 1986). Because of the long stratification periods required for germination, official seed testing rules (AOSA 1993; ISTA 1993) recommend tetrazolium staining or the excised embryo test. For the excised embryo test,

Table 3—*Pyrus*, pear: seed properties

Species	Chilling requirement (days)	Best chilling temp (°C)	Seed size Length (mm)	Seed size Width (mm)	L/W ratio	Seeds/wt /kg	Seeds/wt /lb
P. amygdaliforms	25–27	7	6.7	4.2	1.60	24,000	11,000
P. betulifolia	55–86	4	4.0	2.3	1.74	90,000	41,000
P. calleryana	30–87	7	5.2	2.6	2.00	55,000	25,000
P. communis ssp. *caucasica*	130	4	7.7	4.2	1.83	40,000	18,000
P. communis (domestic)	90	4	8.4	4.8	1.77	22,000	10,000
P. cordata	—	4	4.6	2.6	1.77	86,000	39,000
P. dimorphophylla	65–88	7	5.2	2.8	1.86	77,000	35,000
P. elaeagrifolia	90–127	4	6.7	4.2	1.6	22,000	10,000
P. fauriei	38–88	7	4.7	2.9	1.62	57,000	26,000
P. gharbiana	60–78	7	4.6	2.4	1.92	99,000	45,000
P. koehnii	—	7	4.4	2.4	1.83	79,000	36,000
P. mamorensis	50–58	7	8.9	5.9	1.51	11,000	5,000
P. nivalis	110	4	10.0	4.3	2.32	18,000	8,000
P. pashia	15–43	10	6.5	3.1	2.10	55,000	25,000
P. pyrifolia	120–170	4	8.7	4.4	1.98	26,000	12,000
P. regelii	—	—	11.3	7.6	1.49	7,000	3,000
P. salicifolia	—	4	7.2	4.6	1.59	24,000	11,000
P. syriaca	—	7	9.3	6.2	1.50	9,000	4,000
P. ussuriensis	100	7	7.4	4.5	1.64	20,000	9,000

Sources: Gill and Pogge (1974), Lombard and Westwood (1987), Rudolph (1949), Swingle (1939), Westwood and Bjornstad (1968), Yerkes (1930), Young and Young (1992)

Figure 4—*Pyrus communis*, common pear: seedling development at 1, 2, 3, 6, and 12 days after germination.



embryos should be germinated for 10 to 14 days at alternating temperatures of 18/22 °C (AOSA 1993).

Nursery practice. Seeds are planted thickly, about 13 mm ($^1/_2$ in) deep in a seedbed, and allowed to grow for 1 season. The following spring, plants are dug, their roots and top are cut back, and they are transplanted to nursery rows. After a second season, the rootstock are of correct size for budding in the fall (Hartmann and others 1990). Seedlings of 1+0 nursery stock can be either field-planted or root-pruned at a depth of 15 to 20 cm (6 to 8 in) and transplanted for 1 year (Gill and Pogge 1974). Common pear seedlings may be subject to powdery mildew, which is caused by *Podosphaera leucotricha* (Ellis & Everh.) E.S. Salmon, and by root rots.

Cultivars are propagated by budding or grafting onto rootstocks. Bench-grafting dormant scions onto bareroot rootstocks is no longer common in large-scale nursery production. Nursery trees can be produced more efficiently by T-budding onto field-grown rootstocks in late summer when the bark is "slipping." Chip-budding is an alternative technique for seasons when the rootstock bark is not slipping (Frecon 1982). A whip-and-tongue graft or cleft-graft is commonly used when top-working growing trees in early spring. Scions can be grafted a few centimeters off the ground on a young rootstock, as in side-grafting, or multiple grafts can be placed higher up onto scaffold branches to convert an older tree over to a different cultivar, that is, top-working.

Seedlings of wild native species are used as rootstocks throughout the world (Lombard and Westwood 1987). In North America, seedlings of commercial cultivars of common pear such as 'Bartlett' or 'Winter Nelis' are grown for rootstocks. Seedlings of the Callery pear and birch-leaf pear are often used as rootstocks for Asian cultivars. Seedlings of the Ussuri pear may be used as rootstocks where extreme cold hardiness is needed. Pears are potentially graft-compatible with a number of other genera in the Maloideae subfamily, including serviceberry (*Amelanchier*), cotoneaster (*Cotoneaster*), hawthorn (*Crataegus*), apple (*Malus*), medlar (*Mespilus*), squaw-apple (*Peraphyllum*), mountain-ash (*Sorbus*), and others (Lombard and Westwood 1987; Postman 1992). The common quince (*Cydonia oblonga* Mill.) has traditionally been used as a dwarfing rootstock for edible European pears.

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