REGENERATION

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There are basically two approaches to regenerating aspen stands—sexual reproduction using seed, or vegetative regeneration by root suckering. In the West, root suckering is the most practical method. The advantage of having an existing, well established root system capable of producing numerous root suckers easily outweighs natural or artificial reforestation in the West. Root suckers do not require good seed years or stringent microclimatic conditions (see the VEGETATIVE REGENERATION chapter), and can be produced in much greater abundance and more economically than nursery grown seedlings or transplants. Although suckering precludes the opportunity for genetic improvement of the new stand, it offers the predictability of knowing the type of stand that probably will develop from the regeneration.

However, occasionally, aspen must be established on new sites, or on sites where clonal root systems have died naturally or have been destroyed. Artificial regeneration, using seedlings, or root and stem cuttings is necessary in such cases. Surface mine reclamation, riparian habitat rehabilitation, and production of landscaping planting stock are examples of situations requiring artificial regeneration, if new aspen stands are to be created.

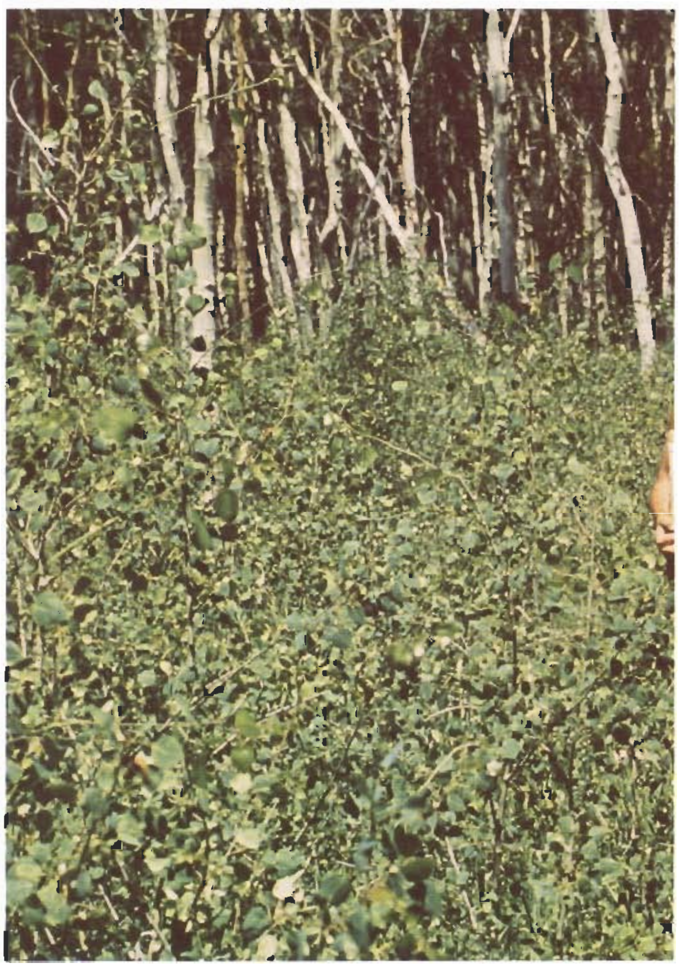

Figure 1.—Clearcutting stimulates the most suckers.

NATURAL REGENERATION

The easiest way to naturally regenerate an existing aspen stand is to rely on root suckering stimulated by removing the existing overstory in a way that will successfully restock the stand and also meet other resource management objectives. The silvical characteristics of aspen (see the MORPHOLOGY and GROWTH chapters) can complicate the choice of silvicultural technique to be used to naturally regenerate an aspen stand. Aspen is intolerant of shade; it grows best in full sunlight. Individual stems also respond well to release, and grow faster when competing vegetation is removed. However, they also are susceptible to diseases infecting the trees through stem wounds caused by logging. Aspen stands are self-thinning, especially at younger ages (Shepperd and Engelby 1983, Walters et al. 1982). Enough sound, undamaged suckers need to result to provide a stand that is well stocked and free of disease and damage, to meet management objectives.

Clearcutting Versus Partial Cutting

Logging greatly stimulates aspen suckering (Baker 1925; Bartos and Mueggler 1982; Crouch 1981, 1983; Jones 1975; Mueggler and Bartos 1977; Sampson 1919; Smith et al. 1972). The number of suckers that appear is directly proportional to the number of stems removed; the greatest number arise after clearcutting (fig. 1). When only part of a stand is cut, sucker production is stimulated on fewer root systems. If apical dominance is extensively broken or reduced by partial cutting, abundant suckers may arise; but they often develop into inferior stands because of competition and shade from residual trees.

In a Utah aspen clone, Smith et al. (1972) compared regeneration on clearcut plots with regeneration on plots from which 67% of the basal area was removed by cutting the larger diameter trees, leaving 41.2 square feet of basal area per acre (9.4 m^2 per ha). Four years after treatment, there were only 27% as many suckers on the partially cut plots as on clearcut plots. Twelve years after treatment, partially cut plots had 39% of the regeneration found on clearcut plots, and sucker heights were 13% less on the partially cut plots (Schier and Smith 1979).

In another Utah study, light partial cutting stimulated suckering; but a very high percentage of these suckers died within a few years (Sampson 1919). Partial cutting an Arizona stand, leaving a basal area of 69 square feet per acre (16 m^2 per ha), did not significantly change the number of suckers surviving 20 years later (Martin 1965).

Partial cutting not only compromises the sustained production of wood products (Walters et al. 1982), but also may severely restrict future silvicultural options in a stand. Once partially cut stands sprout, future entries can not be made without severely damaging the new stand; and any future yields from the residual overstory are forfeited (fig. 2).[1] In addition, growth and vigor of the new stand may be reduced by competition with the residual overstory.

[1] *Data and/or detailed information on file at the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.*

Figure 2.—The 20-year-old saplings in this partially cut stand are being suppressed by the remaining overstory stems; but they would be severely damaged if an overstory removal cut were attempted.

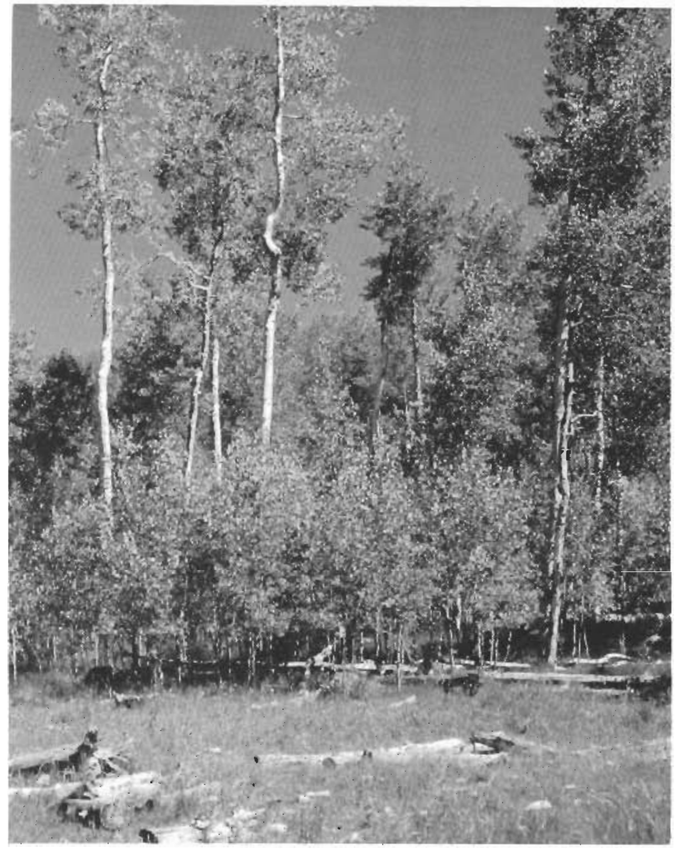

Figure 3.—Heavy partial cutting may adequately regenerate some stands where optimum fiber production is not desired.

In summary, clearcutting is appropriate when the primary management objective is sustained production of forest products—either sawtimber or fiber (Shepperd and Engelby 1983). In such situations, cutting submerchantable stems along with the merchantable ones will maximize sucker production, will minimize the presence of diseased or defective growing stock in the new stand, and will avoid suppression of the new crop by residual overstory stems.

Partial cutting might be feasible in natural, uneven-aged aspen stands that sometimes are found in the central Rockies (Shepperd 1981). If management objectives require vertical canopy diversity or retention of some overstory, partial cutting may result in enough sprouting to adequately regenerate these types of stands (fig. 3). Either individual tree or group selection cutting methods might be applicable (Shepperd and Engelby 1983). Extreme care is necessary to avoid injury to residual stems during logging. Partial cutting is not worthwhile in deteriorating clones where concurrent root system dieback has reduced the clones' ability to sucker (Schier 1975a).

Fire

Burning also can be considered as a natural means of replacing some old stands (fig. 4).

The role of fire in aspen is discussed in the FIRE chapter. Many aspen stands, especially those with only a grass and forb understory, do not readily carry fire (Barrows et al. 1976).[2] Most aspen stands in the West lack the readily flammable fuels needed to produce a fire effective for stimulating regeneration. Even with adequate fuels, the flammability of adjacent grasslands and coniferous forests may make prescribed burning risky. However, where fire can be used with reasonable safety, it is an inexpensive and effective way to naturally regenerate the aspen forest.

A combination of partial cutting and fire is possible. In the Lake States, Perala (1977) reported that a fire in 10 tons per acre (22 t/ha) of dry, evenly distributed, aspen logging slash killed the residual overstory trees and provided favorable conditions for regeneration. Burning should take place as soon after the slash has dried as weather conditions permit. If it is delayed too long, depletion of root carbohydrate reserves by respiration, suckering, and general root deterioration before the burn, will result in poor sucker growth afterwards.

[2]*DeByle, Norbert V. Managing wildlife habitat with fire in the aspen ecosystem. Paper presented at the Fire Effects on Wildlife Habitat Symposium. University of Montana, Missoula, March 1984. Symposium proceedings are in preparation as a USDA Forest Service General Technical Report, to be published by the Intermountain Forest and Range Experiment Station, Ogden, Utah.*

Figure 4.—In some cases, prescribed burning can successfully kill a declining overstory and stimulate the sprouting of a new stand.

To stimulate aspen suckering in mixed stands where a predominantly spruce-fir overstory has been removed, the coniferous slash may be broadcast burned to kill the residual aspen. In this situation, it may be desirable to burn when the duff layer is damp, to avoid killing the many aspen roots commonly growing within the surface organic soil horizon.

Herbicides

Herbicide treatments that kill aspen stems without killing the root system usually result in excellent sucker regeneration (Brinkman and Roe 1975). Aerial spraying with herbicides is an inexpensive substitute for clearcutting, and does not require unusual weather and fuel conditions (DeByle 1976). A single aerial application of a water emulsion of 2-1/2 to 3 pounds (acid equivalent) per acre of a low volatile 2,4-D ester killed nearly all overstory aspen on some study areas in northern Minnesota (Brinkman and Roe 1975). Excellent regeneration resulted.

On a western Wyoming site, 22 years after aspen were killed by spraying with 2,4-D, the sprayed areas had 6,900 more suckers per acre (17,000 per ha) than the unsprayed areas within the same clones. However, there were fewer forbs and shrubs on the sprayed areas (Bartos and Lester 1984).

Aerial application of herbicide, however, subjects the entire forest environment to toxic chemicals, and may have unwanted effects on understory vegetation. Restricted application of herbicide by treatment of individual stems with basal sprays or injection would reduce the environmental impact and, although not yet tested, may result in equally good regeneration.

Girdling

Farmer (1962a) found that severing or girdling roots stimulated suckering distal to that point. The effect of severing was strong; that of bark girdling was weaker and inconsistent. In Utah, plots where all aspen were girdled produced far fewer suckers than plots clearcut or partially cut (Smith et al. 1972, Schier and Smith 1979). Sucker mortality was high on girdled plots; by the 12th year after treatment few suckers were still living. Girdling does not effectively stimulate aspen regeneration for three main reasons.

1. High cytokinin to auxin ratios do not develop in the roots, because, although downward movement of auxin in the phloem is stopped, cytokinins continue to move out of the roots and up the stem through the xylem.

2. Die-back of the root system results, because girdled trees, which can live up to 3 years after treatment, drain the roots of food reserves and other growth factors.

3. Microclimate is unsuitable for sucker development and growth because of shade cast by girdled trees.

Other Methods

In the Lake States, disking strongly stimulated suckering in understocked aspen stands. However, even with abundant light, sucker survival and subsequent stocking usually were poor because of excessive damage to parent roots. Therefore, disking is no longer recommended (Brinkman and Roe 1975; Perala 1972, 1977).

Less severe wounding or cutting of roots also can stimulate suckering without cutting or killing overstory trees (Barth 1942, Farmer 1962a, Maini and Horton 1966a, Sandberg 1951, Steneker 1974). This technique conceivably could be used to promote suckering under existing overstory stands.

In Michigan, Farmer (1962a) found that severing a surface root at a single point strongly stimulated suckering beyond the cut. Perala (1972, 1977) considered root shearing, despite its expense, to be the most successful mechanical site preparation method in the Lake States. Invariably, it resulted in dense aspen regeneration. The parent root system was least disturbed when roots were sheared with a sharp blade in frozen soils. In Arizona, preliminary work by Trujillo[3] suggested that open overmature stands might be regenerated by severing or shearing many roots, each at a single point only. An aspen stand bulldozed in 1979, on the Routt National Forest, Colorado, had 17,000 sprouts per acre in 1984.[1] Preliminary data from a replicated study in progress in Colorado, comparing bulldozer pushing and chainsaw felling, indicates that suckering can be stimulated greatly by bulldozing (fig. 5).[1]

[3]*Unpublished findings by David P. Trujillo, Rocky Mountain Forest and Range Experiment Station, Research Work Unit at Flagstaff, Ariz.*

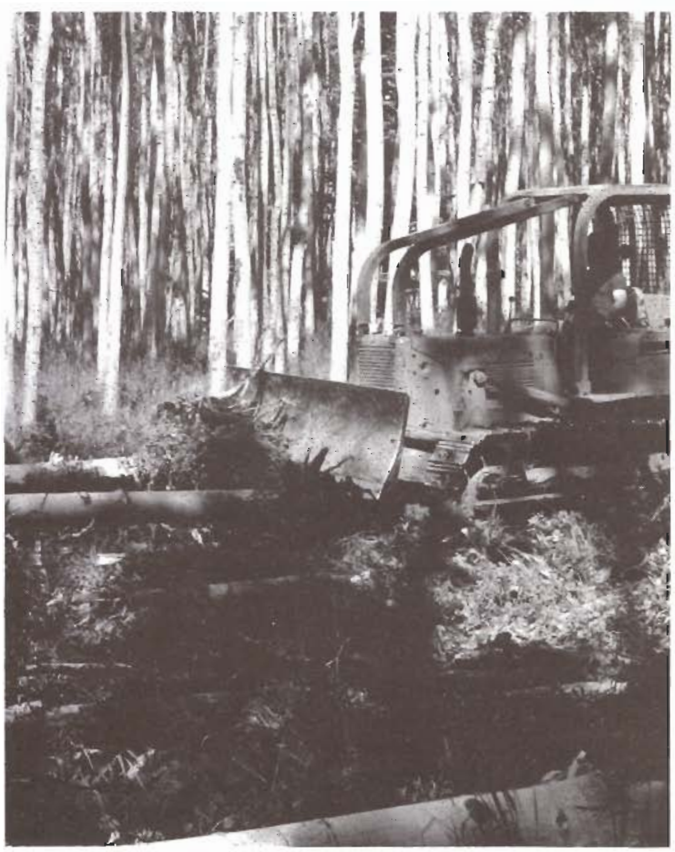

Figure 5.—Regeneration by bulldozing. Stems must be tipped out of the ground. Cutting through soil with the blade will destroy the lateral root system.

Figure 6.—Removing a conifer overstory can stimulate sprouting from a suppressed aspen root system.

In some circumstances, little or no management action is needed to regenerate aspen stands. For example, in grazed aspen stands with established regeneration, marked reduction or exclusion of livestock for a few years may enable these stands to regenerate. Natural sexual reproduction also is possible, although not common, without deliberate management actions. Williams and Johnston (1984) reported natural aspen seedlings on a phosphate mine dump, in southeastern Idaho. The unusual combination of an adequate seed source, friable mineral soil, limited competition from other vegetation, and a continuous supply of soil water made possible the seedling reproduction.

Natural Regeneration of Mixed Stands

In conifer stands that contain an appreciable mixture of aspen, group selection and shelterwood systems may maintain or even increase the aspen component (fig. 6); but, management by individual tree selection will reduce the amount of aspen over time. After clearcutting or a one-cut overstory removal, aspen regeneration is likely to dominate the new forest (Gottfried and Jones 1975). Cutting the aspen along with the conifers probably will result in more suckering than if the aspen were left standing. However, if aspen are not felled, logging damage to aspen roots and increased insolation resulting from conifer overstory removal also may stimulate aspen suckering (see the VEGETATIVE REGENERATION chapter).

Effects of Logging and Other Activities

Concentrated skidding traffic reduces suckering (Zasada and Tappeiner 1969b). After a fire in a mixed conifer forest in Arizona, the network of skid trails and spur roads from salvage logging were still treeless 23 years later (fig. 7), although the crowns of the bordering young aspen forest, about 30 feet (9 m) tall, were starting to close over them. Suckers also were absent from landings. On the Apache National Forest, many clearcuts in the aspen-conifer mixed stands had only patches of aspen 5 to 10 years after logging, despite a general mixture of aspen in the stands before harvesting. Aspen regeneration appeared to have failed where there was heavy skidding traffic or where slash had been piled.

Figure 7.—Concentrated skidding traffic can destroy lateral roots and prevent suckering.

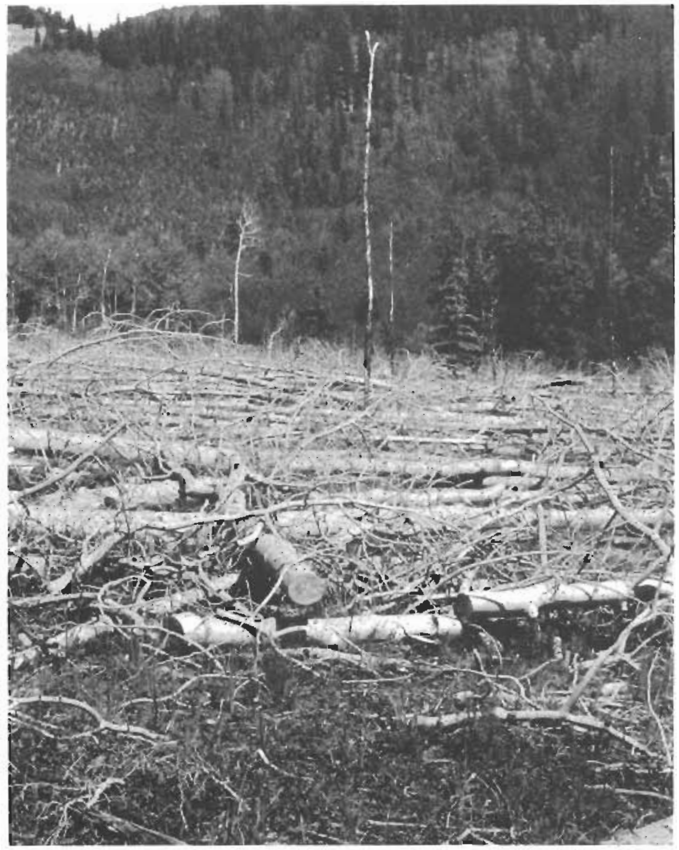

Figure 8.—Heavy concentrations of slash will reduce suckering.

Zasada (1972) found that slash on aspen pulpwood clearcuts in Minnesota did not retard suckering. In the West, however, slash on clearcuts has been somewhat heavier, because usually only sawlogs have been removed, and because of the large volumes of cull material. Suckering can be sparse and sucker growth poor in heavy slash concentrations (Jones 1975, Steneker 1972b). Research in progress has found that heavy slash concentrations (4,000-5,000 cubic feet per acre) can reduce suckering drastically (fig. 8).[1]

Aspen slash usually has been left untreated. It is a negligible fire hazard that decays rapidly and is buried quickly in the dense sucker and understory regrowth. The scattered slash also provides the young sucker stand with some protection from browsing animals.

Grazing, browsing, and trampling by livestock and wildlife can be a serious problem in obtaining aspen regeneration. Limited browsing, however, may result in abnormally dense stocking, partly because of removal of apical shoots and buds (Beetle 1974, Sampson 1919, Smith et al. 1972). Occasional light browsing has little effect on the stem form or height growth of aspen, because a single dominant shoot develops from the uppermost lateral bud below the browsed terminal (Graham et al. 1963, Maini 1966). (See the ANIMAL IMPACTS chapter.)

Time of Treatment

Season of treatment affects number and vigor of aspen suckers. The only time that clearcutting results in substantial suckering during the same growing season as harvest is when aspen is cut in the spring (Baker 1925, Jones 1975, Sampson 1919). Frequently, those suckers that do arise after spring cutting continue growth too long into the fall and then are damaged by frosts. Enough suckers for regeneration generally appear the next year. This reduction in sprouting can be a problem in some vegetation associations where competing understory brush will grow for a full season before aspen suckers arise.

Aspen regeneration in the West generally is adequate wherever aspen is cut during the normal July to November operating season. However, dormant season harvesting could be justified in situations where maximum suckering is critical, such as deteriorating clones, or those subject to extremely heavy browsing or understory competition.

ARTIFICIAL REGENERATION

Aspen planting stock can be propagated from seed or vegetatively. Seed formation creates new genotypes with differing characteristics. Therefore, reproduction from seed results in the full potential for phenotypic variation within the new stand. In contrast, vegetative propagation (e.g., root cuttings) is asexual, and genetic variation during propagation is eliminated. (See the SEXUAL REPRODUCTION, SEEDS, AND SEEDLINGS; VEGETATIVE REGENERATION; and GENETICS AND VARIATION chapters.)

Genotype Selection

Rudolf (1956) suggested criteria for selecting aspen clones for propagation by seed or from cuttings. Where aspen are heavily cankered or attacked by the poplar borer, he suggested selecting clones that show resistance. In old stands, clones that are vigorous and relatively free of heart rot should be chosen. Selected clones should have straight trunks and slender branches (giving less entry to heart rot). Pollen quality should be checked when evaluating male clones for seed production.

Relative time of leafing may be an important consideration in selecting clones in the West. Clones which leaf out earlier than their associates, as well as most high elevation clones, break dormancy at relatively low temperatures. Because physiological threshold temperatures are reached earlier at low elevations, such clones there would break dormancy particularly early. At these lower elevations, clones with low threshold temperatures are likely to be damaged by hard spring freezes after dormancy has broken.

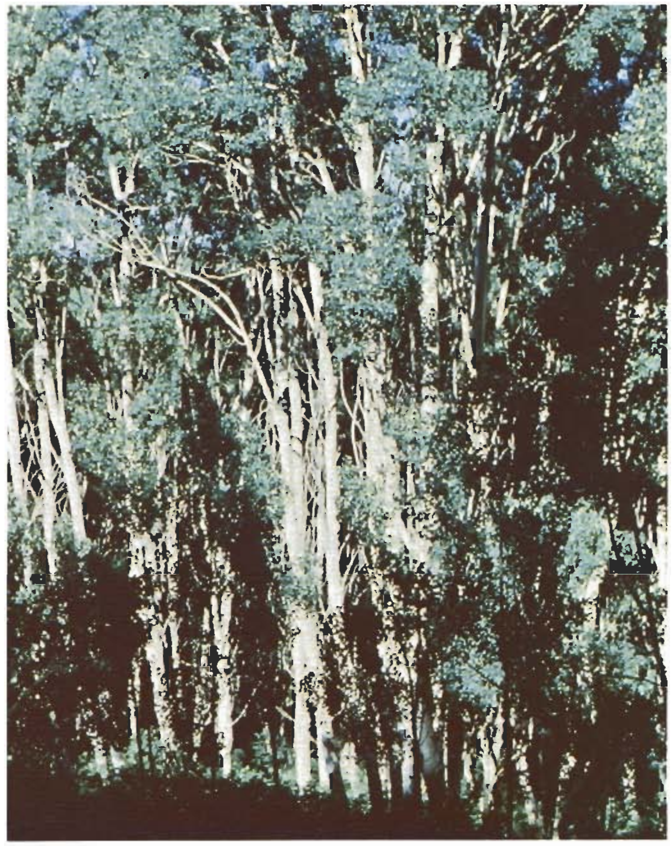

Figure 9.—Clonal differences need to be considered when selecting genotypes for propagation. The branchy growth form of this clone will be passed to its progeny through either vegetative or sexual propagation.

Conversely, late-leafing clones and most clones from low elevations appear to be poor candidates for planting at high elevations, where daytime temperatures are colder. They require relatively high temperatures to break dormancy. At high elevations, these clones may have a very short growing season—too short for adequate growth.

Susceptibility to juvenile diseases should be evaluated among clones. Diseases that are unimportant in a dense, natural sucker stand could be serious in a plantation of, for example, 700 stems per acre (1,730 stems/ha).

Characteristics that are superior in one habitat may be neutral or even unwanted in another. Clonal selection also should be tied to an ecological habitat classification. For example, a natural clone might be described as "84 years old, of good form and superior height on a *Picea engelmanni/Erigeron superbus* habitat, with no indication of decay or insect damage." Planting stock from that clone could be used with considerable confidence on that habitat type, and perhaps on similar types. To use it in an *Abies concolor/Quercus gambelii* habitat might give unsatisfactory results.

An advantage of vegetative regeneration is that the selected clone's performance in a given habitat type can be evaluated in advance (fig. 9). If planting stock is grown from seed, the percentage of the stock that will be well-suited to the intended habitat is unknown. That percentage can be maximized by selecting seed from the best possible female clones that are near good male clones.

There also are advantages to using seedlings. Producing seedlings requires less equipment, labor, time, and space than producing greenwood cuttings (Campbell 1984). A large outplanting of seedling stock will maximize the variation available in the gene pool. This variation benefits reforestation and land reclamation by enhancing the adaptability and survival of the total outplanting. Also, the large amount of planting stock required is more economically grown from seed. Barnes commented that even full-sibling progenies of aspen display considerable genetic diversity.[4]

Once clones have been selected for seed collection, a seed orchard can be established by obtaining sucker cuttings from those clones, planting them in a convenient and suitable location, and treating them for maximum seed production. However, the parent stock should be well evaluated before the seed orchard is established.

Vegetative Propagation

Four methods have been used to vegetatively propagate aspen: root cuttings, stem cuttings, transplanting wildlings, and sucker cuttings.

Root Cuttings

Propagating aspen by planting root cuttings is attractive because of its simplicity. Field plantings, however, have been unsuccessful because of poor sucker production and failure of suckers to initiate new roots. In a Swedish study with *Populus tremula*, planting 5,248 root cuttings produced only 336 rooted plants (Johnsson 1942). An exploratory New Mexico planting was a complete failure. Perala (1978a) was unsuccessful in establishing aspen on old agricultural lands in Minnesota by planting root cuttings, 5 and 40 inches (12 cm and 100 cm) in length, from 10 clones. Initial suckering resulted in one sucker per foot of root length; but mortality was high, and at the end of 6 years only 9% of the suckers survived.

Under greenhouse conditions, Starr (1971) successfully propagated aspen by planting root segments 1/2 to 3/4 inch (1–2 cm) in diameter and 1 inch (2.5 cm) in length. Shoots and roots developed in 6 to 8 weeks; and in 18 months, the suckers grew into small trees. However, this is the only published record found of successful propagating of aspen by planting root cuttings.

Stem Cuttings

Successful reproduction of quaking aspen from dormant stem cuttings has been reported (Barry and Sachs 1968, Schier 1980, Snow 1938); but success is not usual (Barry and Sachs 1968, Barth 1942, Hicks 1971, Maini 1968, Snow 1938).

Using indolebutyric acid (IBA), a rooting hormone, Snow (1938) was able to root a high percentage of cuttings from 1-year-old stump sprouts collected in March, at the first sign of leaf-bud swelling. Results of rooting tests with cuttings taken in January or February usually were negative.

The success reported by Barry and Sachs (1968) was with greenwood stem cuttings from Sierra Nevada clones taken periodically during the growing season. Rooting percentage varied with IBA concentration and stage of shoot growth. They were unsuccessful in rooting dormant stem cuttings except for cuttings taken from a single Mexican clone in April.

Schier (1980) successfully rooted two types of stem cuttings from 2-year-old aspen seedlings—spring shoots and shoots induced to develop by defoliation. A commercial rooting powder significantly increased rooting of both types. Cuttings from spring shoots only rooted when they were treated with the rooting compound. There were significant differences among genotypes in the rooting ability of cuttings from spring shoots.

Stem cuttings, usually taken from the current year's shoot growth, are more difficult to root than sucker cuttings. Hicks (1971) explored anatomical and biochemical differences between sucker cuttings and stem cuttings, but failed to find any reasons conclusive for this. He suspected that differences in rooting ability of the two types of cuttings was a result of different concentrations of root promoting and/or inhibiting substances.

Transplanting Wildlings

The procedure described here is based on observation, common practice, and the experience of John R. Jones at Flagstaff, Ariz. Wildlings should be collected when they are dormant, commonly in the spring. Select healthy looking suckers between 3 and 6 feet (1–2 m) tall. Larger suckers are more likely to die after transplanting. Dig carefully around the base of each selected sucker and locate the parent root. It will probably be within 3 inches (7–8 cm) of the surface. Sever the parent root 6 to 8 inches (15–20 cm) from the sucker on both sides. Remove the sucker and root segment from the ground. If the sucker has developed independent roots at its base, try to keep them intact. Commonly, where the wildling has grown from the root of a living older tree, it will have no roots of its own while it is small. Plant with the root about 6 inches (15 cm) deep. It is advisable to mix sphagnum peat (peat moss) in the soil. Water moderately every 1–2 days the first summer.

The transplanted wildling probably will leaf out later than usual that first spring; but it will almost surely leaf out and will ordinarily persist through the first summer. If it puts out only the small early leaves—those preformed in the buds—plan to get a replacement; it probably won't leaf out again the second year. If it grows some long shoots the first summer, with large leaves, it probably will survive.

[4]*Personal communication from Burton V. Barnes, University of Michigan, Ann Arbor.*

Choosing a wildling from the edge of a clone adjoining parks may provide a smaller, more independent root system. Top pruning and treatment of the planting hole with a rooting hormone also may increase the probability of survival.

To shortcut the process of obtaining aspen planting stock, many commercial nurseries in the West transplant aspen wildlings; failure is common. Schier (1982) studied 12 clones in northern Utah and found that ramets often lacked sufficient independent roots to survive transplanting. The ramets of a few clones, however, were able to develop independent root systems.

Some commercial landscapers reported good survival after transplanting wildlings as large as 3 to 5 inches (7–13 cm) d.b.h. and 18 to 20 feet (5.5–6.1 m) tall (Campbell 1984). They selected ramets with independent root systems that were firmly rooted in all four directions. A 44-inch tree spade was used to remove the wildlings with minimal disturbance to the root systems. After transplanting, the wildlings were given three foliar applications of a complete fertilizer and one hydraulic injection of fertilizer into the soil. The trees also were sprayed with a systemic fungicide.

Sucker Cuttings

Larsen (1943), working with European aspen (*Populus tremula* L.), found that the difficulty of rooting aspen stem cuttings could be overcome by taking cuttings from succulent, young suckers that arise from excised roots. These cuttings rooted with ease. This has become the standard procedure for vegetatively propagating aspen (fig. 10).

Sucker cuttings have been widely used to produce experimental material, sometimes on a rather large scale, with some modifications in technique practiced by different investigators (Schier 1978b). Certain basic requirements must be met. Don't let the root cuttings dry out or mold. Plant them in a freely drained medium. Maintain moderate temperatures. When the suckers are still small, cut them from the parent root and plant in a freely drained medium. Keep the humidity high and the temperature moderate. When they have rooted, replant them outdoors or individually in containers. At all times, maintain sanitary conditions to keep pathogens under control.

Root collection.—The diameter of collected roots is not very critical. Root segments smaller than 1 inch (2.5 cm) in diameter may produce more suckers per lineal foot (Benson and Schwalbach 1970, Sandberg 1951). However, Starr (1971) found little size-related difference in the sucker production of root cuttings 1/4 to 2 inches (0.6–5.0 cm) in diameter from Wyoming clones. Zufa (1971) recommended diameters of 1 to 2.5 inches (2.5–6.4 cm).

Root cuttings from some clones produce several times more suckers per foot than those of others (Schier 1974, Schier and Campbell 1980). Density of suckers also is a function of collection date (Schier and Campbell 1980, Tew 1970a). The number of rootable suckers produced

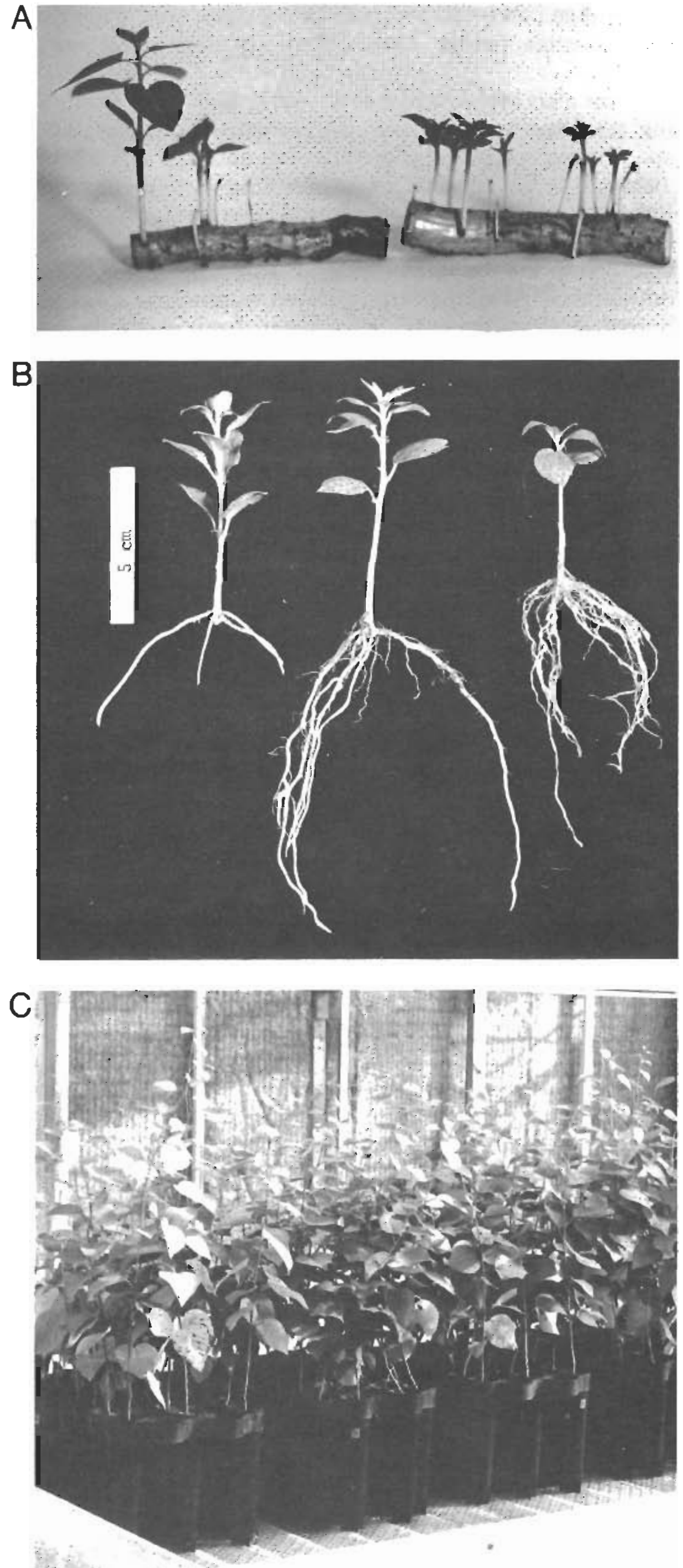

Figure 10.—Three steps toward producing aspen planting stock from sucker cuttings: (A) suckers arise on properly treated root segments, (B) excised suckers develop roots when planted in the proper media and are kept well watered, and (C) container-grown aspen, planted as root cuttings about 3½ months before this photograph was taken.

by cuttings from any clone varies with the date of collection; and the best and poorest dates vary from clone to clone (Schier 1973d, Schier and Campbell 1980, Tew 1970a, Zasada and Schier 1973). Schier (1978b) avoided collecting roots during the spring flush of shoot growth when few suckers are produced. Benson and Schwalbach (1970) recommended autumn as the best time to collect roots.

Root storage.—Many aspen areas in the West are snow covered until May or June, making it difficult to collect roots until late spring. In those locales, roots probably should be collected in October, stored, and then planted in March or April.

In Minnesota, Sandberg (1951) produced and rooted suckers without difficulty from roots collected in November and stored in moist soil at 40°F (4°C) for 75 days. In Wisconsin, Benson and Schwalbach (1970) dug up roots in November and stored them in sand in polyethylene bags, some in refrigeration at 30–40°F (−1°C to 4°C), and some in an unheated building. Taken from storage in April, the roots suckered very well, and the suckers rooted normally. Roots died when overwintered in a deep freeze (Benson and Schwalbach 1970).[5] Schier and Campbell (1978b) made a comprehensive study of the effect of cold storage on suckering. They found that the roots of 10 Utah clones collected in spring, summer, or fall, could be stored safely for prolonged periods. Roots collected in October and stored at 35°F (2°C) for 175 days did not show any significant loss in suckering capacity.

Roots should be treated with a fungicide before either storage or planting to reduce the danger of mold or other disease. If sand or other medium that may be contaminated is used for storing the root segments, the medium should be sterilized with a soil fumigant or should be autoclaved before use. If a commercial medium, such as perlite, is used for storage, sterilization is not needed unless there is reason to believe it has been contaminated. The storage medium should be moist to avoid drying the roots, but not too wet to avoid disease problems.[5]

Root preparation.—To reduce the incidence of disease, the roots should be scrubbed clean with a soft brush, cut into planting pieces not longer than 6 inches (15 cm), and the pieces should be dipped in a fungicide solution (Benson and Schwalbach 1970).[6] Wounds and cuts are then coated with a micro-crystalline wax. Clean tools should be used for cutting. Without careful treatment, insects and decay may destroy entire lots of root segments and suckers (Farmer 1963b, Larsen 1943). Roots from occasional clones decay readily regardless of treatment, and do not produce a satisfactory yield of usable suckers (Schier 1978b).

Root planting.—Planting depths of root segments may vary from 0.6 inch (1.5 cm) in vermiculite (Schier 1978b) or sand (Tew 1970a) to "just covered" (Benson and Schwalbach 1970). They should be covered sufficiently to keep them moist but shallow enough to harvest the suckers conveniently.[5]

Media, in sterilized plastic or wooden flats, successfully used in sucker propagation have ranged from peat (Larsen 1943), to coarse sand (Tew 1970a, Zufa 1971), to fine sand (Maini and Dance 1965, Maini and Horton 1966b), to a coarse sandy loam (Sandberg 1951). Barry and Sachs (1968) and Schier (1978b) used vermiculite with good results. Zasada and Schier (1973) used a 1:1 mixture of vermiculite and perlite. Benson and Schwalbach (1970) recommended a 1:1 mixture (by volume) of vermiculite and sand.

Greenhouse environment.—Maini and Horton (1966b) found constant temperatures from 64° to 87°F (18°C to 31°C) were suitable for suckering root cuttings. Zufa (1971) produced suckers successfully with greenhouse temperatures fluctuating between 60° and 90°F (16°C and 32°C), and relative humidities from 30% to 90%. Zasada and Schier (1973) tested three temperature regimes on cuttings from three Alaskan clones, and had good results at day/night temperatures of 77°/59°F (25°/15°C) and 86°/68°F (30°/20°C). Schier also used the day/night temperature regime of 77°/59°F (25°/15°C) with good results, using roots from Utah and Wyoming clones. Sandberg (1951) found light intensity was unimportant in bringing suckers to readiness for cutting from the root pieces. Benson and Schwalbach (1970) recommended watering the planted root cuttings only enough to keep them from drying out. Overwatering increased the risk of disease.

Severing the suckers.—Suckers begin emerging about the second week after the root pieces are planted (Benson and Schwalbach 1970, Larsen 1943, Sandberg 1951, Zufa 1971). Maximum production occurs in 5 or 6 weeks (Schier 1978b). Suckers may be cut from the root pieces for rooting when they are as short as 0.8 inch and as long as 4 inches (2–10 cm) (Schier 1974, Zufa 1971). Benson and Schwalbach (1970) recommended cutting them off when they are 1 to 2 inches (2.5–5.0 cm) long and have two developing leaves. The cutting tool used should be clean, and sterilized after suckers from each flat have been harvested.[5]

Rooting the cuttings.—Coarse sand (Farmer 1963b), loam (Zufa 1971), shredded sphagnum moss,[4] mixtures of sand and vermiculite (Benson and Schwalbach 1970), and perlite and vermiculite (Barry and Sachs 1968) all have been used for rooting sucker cuttings. The rooting medium is placed in well-drained, sterilized, plastic or wooden containers. Flats or trays that can hold 100 or more cuttings seem to be the most suitable for large-scale production. However, single cuttings in small containers have the advantage of not needing transplanting after the roots develop. They can be left in the containers until the cuttings have a well-developed root system and have substantial top growth. Using this procedure, the roots are not disturbed by transplanting to another container when they are most fragile, and a propagation step is eliminated. Barnes successfully

[5]*Personal communication from Dean W. Einspahr, Institute of Paper Chemistry, Appleton, Wisc.*

[6]*They used 1 1/2 tablespoons of Captan 50W per gallon of water. Other fungicides probably are also satisfactory.*

propagated single aspen in Jiffy-7 peat pots[7] 1.75 inches (4.5 cm) in diameter by 2.125 inches (5 cm) high.[4] Zufa (1971) rooted cuttings in polystyrene tubes.

Generally, hormone treatments are not necessary for adequate rooting. However, suckers from roots of some clones, collected on some dates, have not rooted well (Farmer 1963b, Schier 1974, Schier and Campbell 1980, Tew 1970a). To overcome this problem, a higher rooting percentage, and more and larger roots per rooted sucker, will result from treating the suckers with indolebutyric acid (IBA) (Farmer 1963b). Cuttings can be treated either by dipping the base in talcum powder containing IBA or by quickly dipping the ends in alcoholic solutions of IBA (Schier 1978b). Commercial powder preparations of IBA are available.

A misting bench, giving an intermittent mist, is most suitable for rooting sucker cuttings (Farmer 1963b, Schier 1978b). Temperatures should be kept between 70° and 80°F (21°C and 27°C), although night temperatures can be slightly lower. If misting facilities are not available, sucker cuttings can be rooted in chambers covered with clear plastic. Periodic watering will maintain a high humidity in the chambers, which will keep the succulent cuttings turgid. The simplest chamber is a rooting tray sealed in a plastic bag (Benson and Schwalbach 1970). Clear plastic boxes 3 × 6 × 12 inches (7.5 × 15 × 30 cm) have been used as rooting chambers.[5] The bottoms have drainage holes, and the lids have air-holes. The boxes are partly filled with a sterilized vermiculite-sand mixture. The 100 suckers in each box are watered as needed, and nutrients are added once only, after they have rooted. Once rooted, the lids are removed to make room for the growing tops. Sucker cuttings from most clones produce well-developed root systems in 2 to 3 weeks (Benson and Schwalbach 1970, Schier 1978b). As might be expected, there is considerable clonal variation in rooting ability (Schier 1974, 1980).

Transplanting.—Unless single cuttings have been rooted individually, sucker cuttings must be transplanted soon after roots form. If the cuttings cannot be transplanted immediately, they are kept from outgrowing their trays by restricting moisture and nutrients (Benson and Schwalbach 1970) and lowering temperatures.[4] After transplanting to nursery beds, the cuttings often reach heights of 3 to 5 feet (1.0–1.5 m) by the end of the summer. They are cut back when lifted. Fertility standards for quaking aspen nursery beds have been given by Williams and Hanks (1976) and Wyckoff and Stewart (1977).

An alternative to nursery beds is transplanting rooted cuttings into individual containers. With increased use of container stock for large-scale reforestation, containers of all sizes and shapes have become available. Schier (1978b) successfully used a tube 2.5 inches in diameter by 10 inches in depth (6.4 × 25.5 cm) filled with a 1:1 vermiculite-peat moss mixture. Planted cuttings were treated with a complete commercial fertilizer. After one growing season, the containers were filled with roots, and the young trees could be outplanted.

[7]Trade names are used for the benefit of the reader, and do not constitute an official endorsement or approval of any product or service by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

Producing Seedlings for Planting

Collecting Seed

First, female clones that bear seed must be selected. They should have desirable characteristics and lack any notable shortcomings. Some female clones are not readily recognized, because they rarely flower in nature (Einspahr 1962). Some that flower bear little good seed, perhaps because the nearest synchronized pollen source is too far away (Baker 1918b, Barth 1942, Reim 1930). At least in Norway, seed production is often severely reduced by insects (Borset 1954).

Pauley (1955) was readily able to obtain good seed from every western state in which aspen grows. During 2 years of collecting, Barnes found many clones bearing good seed throughout the aspen areas of Utah.[4] He also obtained seed from Alberta and Alaska.

Mature capsules that are plump and rounded near the base, and have erect points, commonly contain good seed (Baker 1918b, Barth 1942, Borset 1954). Mature capsules do not contain good seed if they are somewhat flattened and taper rather evenly from base to point. Many seedless capsules have bent or crooked tips.

Baker (1918b) observed that edge trees or isolated trees are more likely to flower than those within dense stands. Therefore, thinning might induce or increase flowering in desirable female clones. Also, some trees that normally do not flower sometimes may be induced to flower by girdling (Einspahr 1962, Jensen 1942). Jensen did this by drawing a wire tightly around the tree. The wire was underlaid by a light metal strip to prevent killing the tree. However, for seed production, simply stripping a ring of bark from a few trees each year will cause little damage to most large aspen clones.

Seed is borne in late spring. Time of flowering is not a useful predictor of collection time. Faust (1936) reported the interval from flowering to seed maturity was 6 to 10 weeks in New York. Time of collection is critical. When the seed has ripened, one windy day can disperse the whole crop (Barth 1942, Borset 1954). Barth (1942) advised collecting catkins when some capsules are beginning to open.

Borset (1954) described a straightforward procedure for timing seed collection. When trees approach maturity, collect sample catkins and spread them in a warm dry room. If catkins are collected too early, they will wither. If they are collected nearer to maturity, the capsules will open after a time and the cottony seeds will well out. When that happens, catkins on the trees should be collected for seed extraction.

If relatively few seeds are wanted, branches can be collected and stood in water. The cut ends should be trimmed daily to prevent clogging. If mature, the capsules will open in 2 or 3 days, and the seed can be collected. If insufficiently mature when the branches are cut, some catkins will wither or yield a low percentage of viable seed (Borset 1954, Roe and McCain 1962). High air temperatures (68° to 104°F (20° to 40°C)), gentle ventilation, and low relative humidity hasten the ripening process. The catkins should not be exposed to full sunlight (Food and Agriculture Organization of the United Nations 1979).

Sowing the catkins themselves, or sowing seed with the cotton adhering to them, works with larger-seeded species of *Populus*, but is very unsatisfactory with aspen (Barth 1942). Vacuum cleaners are satisfactory for separating the cottony seed from catkins on cut branches (Roe and McCain 1962) or even from catkins spread on a floor (Borset 1954). In the latter case the vacuum head is held a few inches above the layer of catkins so that the seed and cotton are sucked in, but the catkins remain.

Aspen seed can be separated from the cotton by rubbing it over a fine mesh wire screen (Faust 1936) or by using an air stream and a series of screens (Einspahr and Schlafke 1957, Roe and McCain 1962). Only a small percentage of seed is extractable by rubbing. An air stream and screens is more efficient. From top to bottom, the screens are 20-mesh, 40-mesh, and 60-mesh. A high velocity stream of air tumbles the cottony seed in the upper screen; the seeds are collected on the 40- and 60-mesh screens.

Within at least some species of *Populus*, the larger seeds germinate more and grow faster (Farmer and Bonner 1967, Faust 1936), which should result in better seedling establishment. Therefore, if quaking aspen seed is screened and the smaller are rejected, more desirable results may be obtained.

Drying and Storing Seed

Viability of aspen seed can be maintained for several years by proper drying and cold storage in sealed containers. Faust (1936) found that seed stored better if it had been dried immediately after extraction. Moss (1938) recommended drying for 2 to 3 days at 75°F (24°C). Eight hours of forced air drying is effective; a hair dryer was used in pilot tests (Marjai 1959).

Considerable information has been published on storage conditions (Barth 1942, Benson and Harder 1972, Borset 1954, Busse 1935, Faust 1936, Moss 1938, Wang 1973). Campbell (1984) air dried aspen seed for 2 days and then stored it in a sealed plastic envelope at 36°F (2°C). Germination rate initially was 94%; after 4 years of cold storage, the seeds still had 82% germinability. Temperatures below freezing also are satisfactory for long-term storage. Benson and Harder (1972) reported germination only slightly reduced after 4 years storage at −11°F (−24°C).

Sowing Seed for Bare-root Stock

Barth (1942) described nursery practices for aspen in Norway. Later, the Institute of Paper Chemistry developed an improved nursery system (Benson and Einspahr 1962, Einspahr 1959) and tested it on a commercial scale (Benson and Dubey 1972). An outline of that system as described by Wyckoff and Stewart (1977) follows.

1. Prepare a fine smoothed seedbed. Incorporate a non-burning granular fertilizer into the soil.
2. Fumigate the seedbed with methyl bromide. Aerate for 3 days before seeding.
3. Place a frame around the seedbeds. Sow seed on a still day at a rate of approximately 20 seeds per square foot (215/m^2). After seeding, gently rake seedbed on the contour.
4. To provide shade and protect seedlings from wind and splashing, cover the bed with muslin supported by 1/2-inch (1.3-cm) hardware cloth on a lath frame, all of which is supported by the frame mentioned in step 3.
5. During the first 6 days, water the seedbed several times a day, keeping the surface constantly moist. Afterwards, water beds once a day. If necessary, use acid injection in the irrigation system to maintain the pH between 5.5 and 6.0.
6. Fertilize two more times before lifting. Follow a schedule for applying fungicides and insecticides.
7. Remove muslin after 3 weeks, hardware cloth after 7 or 8 weeks, and framing boards after 10 or 12 weeks.
8. Lift trees in the fall, cut back to about 18 inches (45 cm) in height, prune roots if necessary, and bundle. Bundles are stored over winter in an unheated building where they are heeled-in in sand, watered, and treated with a fungicide.

In the West, where some planting sites are snow-covered well into May or later, an unheated building may not provide suitable storage. In this case, refrigerated storage may be necessary to offset increasing springtime temperatures.

Container-grown Seedlings

An alternative to bare-root planting stock from a nursery are greenhouse-grown container trees. A container seedling is in better physiological condition than a bare-root seedling (Tinus and MacDonald 1979). The container seedling has an undamaged, intact root system, and the original root-to-soil contact is maintained. The container seedling should have a better chance of surviving in the often dry and otherwise harsh environments in the West.

Schier successfully used 2.5- by 10-inch (6.4- × 25.5-cm) tubes and a 1:1 vermiculite-peat moss medium to grow containerized aspen seedlings, the same procedure he used to propagate sucker cuttings (Schier 1978b). The seed was covered with about 1/8-inch

(30 mm) potting soil mix and was lightly watered. Greenhouse temperatures ranged from 60°F (16°C) at night to 77°F (25°C) during the day. After germination, each seedling was fertilized with a dilute solution of a liquid fertilizer to avoid burning the tender plant. Weekly applications of full strength fertilizer solutions were started after 5 to 7 days. Seedlings started in the spring grew from 12 to 18 inches (30 to 45 cm) before bud set in the fall; the containers were full of roots; and the plants had a satisfactory shoot-root ratio.

Site Preparation

Competition from herbaceous plants, particularly sod-forming grasses, in both natural regeneration and plantations of aspen will seriously reduce growth and survival (Aldhous 1969, Bailey and Gupta 1973, Benson 1972). Benson (1972), in Wisconsin, noted that good sod control before planting and for 2 years afterwards resulted in average 2-year heights of 8 feet (2.5 m). Some herbicides may be used; but many harm the aspen. Cultivation works well but is expensive.

Plantation Spacing

Initial spacing may vary from 5 × 5 feet (1.5 × 1.5 m) to as much as 10 × 10 feet (3 × 3 m). However, wide spacing may result in limby trees and reduced quality of the aspen for sawlogs and veneer. Trees with long-lived lower branches are likely to have more degrade from wood stain (Hoók and Sucoff 1966). Barth (1942) recommended planting at a spacing of 5 × 5 feet for production of high quality timber (match bolts) in Norway.

Limbiness of the aspen plantation is not detrimental if the purpose is simply to establish aspen on an area for esthetics, to provide wildlife habitat, or to provide a conifer nurse crop. A wide spacing of 9 × 9 feet (2.8 × 2.8 m) requires planting fewer than one-half as many trees as one of 6 × 6 feet (1.8 × 1.8 m)—538 compared to 1,210 per acre (1,330 versus 2,990 per ha).

If the economics of planting at wide spacings are attractive but close spacing is wanted, trees might be planted at 10 × 10 feet (3 × 3 m), for example, then cut back at 5 years (Benson 1972) or at 10 or 12 years (Einspahr and Benson 1968) to provide a much denser sucker stand. This can only be attained at a cost of 5 to 12 years growth.

Planting

There is little published information about planting aspen. In Norway, Barth (1942) recommended planting in dug holes as early as possible in the spring. In Illinois, Gilmore (1976) found that cottonwood seedlings planted in auger holes made better early growth and survived better than those planted with dibbles. In the West, container-grown rooted sucker cuttings were outplanted in the spring of 1976, on north slopes of phosphate mine spoils in southeastern Idaho, on sites that receive about 18 inches (45 cm) annual precipitation. Site preparation included ripping, harrowing, and fertilization. By the fall of 1977, the aspen had grown less than 1 foot (30 cm); but more than 80% survived.[8] Poor height growth probably resulted from grass competition. Survival appeared good in 1983; the aspen were outgrowing the competition with leaders of approximately 1 foot (30 cm) each year.

[8]From records of the Mine Spoil Reclamation Project, Intermountain Forest and Range Experiment Station, Logan, Utah.