Vegetative Propagation

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9

For the past 30 years, interest in the propagation of native plants has been growing. Many desirable and ecologically important species, however, are difficult or very time consuming to propagate by seeds. Thus, nursery growers may want to investigate how to propagate a species of interest by vegetative propagation. This can be done by combining classic horticultural propagation techniques with an understanding of the ecological and reproductive characteristics of the species. By investigating how a species perpetuates under natural conditions, nursery growers may be able to vegetatively propagate the species and produce nursery stock in situations when there are constraints on using seed propagation.

Many native plants naturally propagate vegetatively (that is, without seeds or spores) as a method of ensuring reproduction. Vegetative propagation is commonly found with species that have short seed life, low seed viability, or complex or delayed seed dormancy strategies. Species that inhabit ecosystems with drastic weather patterns, short growing seasons, and endure fires and other disturbances often reproduce vegetatively. All new daughter plants that arise from vegetative propagation are genetically identical to the mother (donor) plant, and these resulting individuals are known as "clones" (figure 9.1).

Nursery managers can make use of a plant's ability to regenerate vegetatively. The following situations favor vegetative propagation over seed propagation:

Joanne Bigcrane of the Confederated Salish and Kootenai Tribes in Montana by Tara Luna.

Figure 9.1—*Pacific yew is a species that is propagated by stem cuttings: (1) because it has very complex seed dormancy; (2) to obtain a larger plant in a shorter period of time; and (3) to perpetuate certain genotypes or individuals exhibiting high levels of taxol, a medicinal product found within the bark.* Photo by Thomas D. Landis.

- Seed propagation is difficult, very time consuming, or few viable seeds are produced.
- Larger nursery stock is needed in a shorter period of time.
- An individual, unique plant needs to be propagated.
- There is a need to shorten time to flower for seed production.
- A uniform stock type is needed.
- Specific genotypes are desired.
- Disease-free nursery stock is required.

Some disadvantages of using vegetative propagation include:

- Greater production costs than seed propagation, usually because of increased labor.
- Reduced genetic diversity.
- Specialized propagation structures may be required, depending on the species or time of year.

In general, vegetative propagation can be done with pieces of stems, leaves, roots, bulbs, corms, tubers, and rhizomes. Many factors, however, contribute to successful vegetative propagation of native plants. The type of vegetative material used, the time of year that material is collected, how it is handled and manipulated to induce rooting, and proper application of the correct environmental conditions all affect vegetative propagation. In addition, how plants are handled after rooting also plays an important role.

Because vegetative propagation is more costly than growing seedlings, the production system must be efficient. A general rule of thumb is that at least 50 percent rooting must be obtained to produce cuttings economically. If rare species or individual plants are being propagated, however, costs may be less important. Consider these methods to reduce production costs:

- Develop a smooth production line, from the collection of material to the final product.
- Train nursery staff how to properly collect, pro-cess, plant, and grow material.
- Build a dibble for making holes in the rooting medium.
- Control waste caused by poor propagation or growing practices.
- Lift and harden cuttings properly to reduce mortality.
- Develop a good system for overwintering cuttings.
- Keep good records to improve your results and to document production costs.

The following discussion will provide a broad overview of vegetative propagation. More specific details on vegetative propagation of particular plants can be found in Landis and others (1999) and volume 2 of this handbook.

STRIKING CUTTINGS

A cutting is the portion of a plant that is collected, treated, and planted to develop into a new intact plant complete with stems, leaves, and roots. Cuttings can be collected from mother plants in the wild, or special donor plants can be cultured in the nursery. Selection of mother plants, whether in the nursery or the wild, must be done carefully; it is just as important as the origin of seeds to ensure that nursery stock is well adapted to the outplanting environment. Collection of cuttings should follow the same ethical guidelines as collection of seeds to establish proper genetic diversity and sustainability of wild populations. See Chapter 7, *Collecting, Processing, and Storing Seeds*, for guidelines. In addition, the ability of cuttings to root is often clone specific, so it is important to record the origin of cuttings and subsequent rooting success.

Striking is the process of placing the cutting into soil or a rooting substrate. Often, propagators will say that cuttings have been "struck" to indicate that the cuttings have been placed in the rooting substrate.

SHOOT OR STEM CUTTINGS

Shoot cuttings, also referred to as stem cuttings, are the most common type. These cuttings can be broadly placed into three categories depending on the time of year they are collected (figure 9.2). Hardwood cuttings are collected when plants are dormant, from late autumn through early spring. Softwood cuttings are collected in late spring and early summer when stems and leaves are actively growing. Semihardwood (greenwood) cuttings are collected in late summer and early autumn when stem tissues have hardened and terminal buds have formed. Within each category, several cutting types are possible. Both deciduous and coniferous (evergreen) species can be propagated with these types of cuttings.

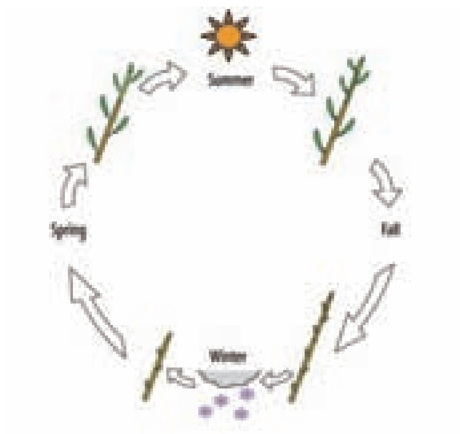

Figure 9.2— *"Hardwood" cuttings are dormant wood collected in winter. In late spring and early summer, new growth that occurs from the hardwood and bends but does not snap when bent is considered "softwood." In late summer and early autumn, as softwood matures, subsequent cuttings from that wood are termed "semihardwood." In late autumn, semihardwood further hardens for winter, becoming dormant wood from which hardwood cuttings can be made.* Illustration by Steve Morrison.

Hardwood Cuttings

Deciduous Species

Deciduous hardwood stem cuttings are the easiest, least expensive type of cuttings because they are easy to prepare, are not as perishable as softwood or semihardwood cuttings, can be stored in coolers or shipped if necessary, and require little or no special equipment during rooting. They are sometimes struck directly on the outplanting site or brought back to the nursery to grow as bareroot or container stock.

If hardwood cuttings are struck directly on the outplanting site, they can be live stakes (12 to 16 in [30 to 40 cm] long), poles (12 to 16 ft [3.6 to 4.9 m] long), or branched cuttings (2 to 6 ft [0.6 to 1.8 m] long). These cuttings are collected and outplanted during late autumn to early spring when the cutting is dormant and the soil at the outplanting site is wet. Live stakes and branched cuttings need to be long enough to reach moisture in the soil profile and are usually driven into the ground with a mallet with only three to four nodes (buds) above ground. Poles are much longer and are driven deep enough so they can remain in contact with the water table during the driest part of the year. Hardwood cuttings of willows and cottonwoods are commonly used this way in restoring riparian areas.

If hardwood cuttings are struck in the nursery, they can be straight, heel, or mallet cuttings (figure 9.3). Straight cuttings are made from straight hardwood stems and are the most common type for easy-to-root species. Heel cuttings are made from side shoots on stems that are 2 years old. To make a heel cutting, pull the side shoot away from the tip so that there is a section of older wood at the base of the cutting. Mallet cuttings include a cross-section of older stem at the base of the side shoot (figure 9.3).

Figure 9.3—*Straight, heel, and mallet cuttings. Straight cuttings are used on easy-to-root species, while heel and mallet cuttings are commonly used on more difficult-to-root species.* Photo by Tara Luna.

All hardwood stem cuttings have an inherent polarity and will produce shoots on the distal end (nearest the bud) and roots on the proximal end (nearest the main stem or root system). If planted upside down, the cutting will not root. When using straight or live stake deciduous cuttings, the tops and bottoms of the stems need to be distinguished. The absence of leaves can make it difficult for nursery workers to discern. The solution is to cut the bottoms straight across the base of a node and cut the tops at an angle (figure 9.4).

Coniferous Species

Hardwood cuttings of evergreen conifers are usually taken in late winter to early spring. Unlike hardwood cuttings, evergreen cuttings must be struck into a special rooting environment (see Chapter 4, *Propagation Environments*) as soon as possible because they cannot be stored for any length of time. Evergreens are best rooted in special rooting environments after being wounded or treated with rooting hormone (described in the following paragraphs). Usually, cuttings are 4 to 8 in (10 to 20 cm) long with all leaves removed from the lower half. Straight, mallet, and heel cuttings are also used with evergreen species (figure 9.3).

Softwood Cuttings

Prepared from the new growth of deciduous or evergreen species, softwood cuttings generally root easier than other types of cuttings but require more attention and a special rooting environment. The best cutting material has some degree of flexibility but is mature enough to break when bent sharply (figure 9.5). Extremely fast-growing tender shoots are not desirable.

Herbaceous stem cuttings are softwood cuttings made from nonwoody plants. They are handled in the same way as softwood cuttings (figure 9.6A). Many succulent desert plant cuttings, such as those from cacti, are easily propagated; cuttings should be allowed to develop callus for a week before inserting the cutting into rooting media. They root readily without misting or high humidity (figure 9.6B).

Semihardwood Cuttings

Semihardwood (greenwood) stem cuttings are those made from leafy broad-leaved evergreen plants and leafy summer and early autumn wood from deciduous plants. Cuttings are taken during the late summer and autumn just after a flush of growth has taken place and the wood is partially matured. In many cases, the terminal bud has formed for the next growing season (figure 9.7).

ROOT CUTTINGS

Although not used as much as other types of cuttings, root cuttings can be made by dividing roots into individual segments containing dormant shoot buds capable of developing into new plants. Root sections are collected from late autumn to early spring before new tissue emerges from buds.

Figure 9.4—*Polarity means cuttings will produce shoots on the distal end (nearest the bud) and roots on the proximal end (nearest the main stem or root system). It is important that the cutting is oriented properly when planted; the absence of leaves can make this an easy but important point to miss. The solution is to cut the bottoms straight across the base of a node and cut the tops at an angle.* Photo by Tara Luna.

Root cuttings are planted horizontally in containers with the dormant leaf buds on the upper side. Some root cuttings are also planted in the containers vertically, but it is important to maintain the correct polarity (figure 9.8). To ensure that root cuttings are planted correctly, cut the upper end of the cutting horizontally and cut the basal end diagonally. Root cuttings generally do not require a special rooting environment unless shoots are cut from the root piece and treated as a stem cutting.

WHAT TO CONSIDER WHEN SELECTING CUTTINGS FROM MOTHER PLANTS

A variety of factors can greatly influence the rooting success of cuttings. Collectors need to be aware of these factors and, with experience, will be able to discern the right type of cutting material to collect. Important factors include seasonal timing, juvenility, plagiotropism, species, and cutting size and quality (figure 9.9).

Some species can be readily propagated from cuttings collected in any season of the year, while others have very specific seasonal trends when they will form roots. For any given species, small experiments are required to determine the optimum time to take cuttings, which is related to the physiological condition of the donor plant at collection time rather than any given calendar date. Recordkeeping is important to improve rooting results from year to year.

All plants progress from a juvenile phase (incapable of producing flowers) to a mature or adult flowering phase. Different parts of the plant, however, can be at different stages of maturity at the same time. Sometimes the juvenile phase can be distinguished from the adult phase by differences in leaf shape or color or by the overall habit of the plant. The juvenile phase is easily seen in junipers in which juvenile leaves are feathery and needle-like and often differ in color from mature leaves that are more rounded at the tips. In other conifers, juvenile wood is usually found on the lower portion of the tree crown and the adult, cone-bearing wood is located in the upper crown. In deciduous plants, juvenile wood is found near the stem base or root crown and can be discerned as the long, non-flowering shoots (sucker shoots). Cuttings collected from this region of the plant root more easily than those from older, mature wood. In some cases, many difficult-to-root species will root only from stems collected from young seedlings. Hedging or coppicing is the practice of regularly cutting back donor plants to maintain juvenile wood and is an efficient means of generating many long, straight cuttings from a limited number of plants. Donor plants in natural stands can be selected for hedging on an annual basis if cuttings will be collected from the area for several years (figure 9.10). Otherwise, mother plants can be held in the nursery and used as a source of cuttings.

Plagiotropism is the habit of a cutting to continue to grow in the direction it was growing on the donor plant. In some species plagiotropism is strong but in other species it is weak. Similarly, plagiotropism can be strong or weak depending on the original position of the cutting on the donor plant. Often, plants produced from cuttings from lateral shoots will maintain a later-

Figure 9.5—*(A) Softwood stem cutting material has some degree of flexibility but is mature enough to break when bent sharply. Tender softwood shoots that do not break should not be used. (B) Rooted softwood snowberry stem cutting.* Photos by Tara Luna.

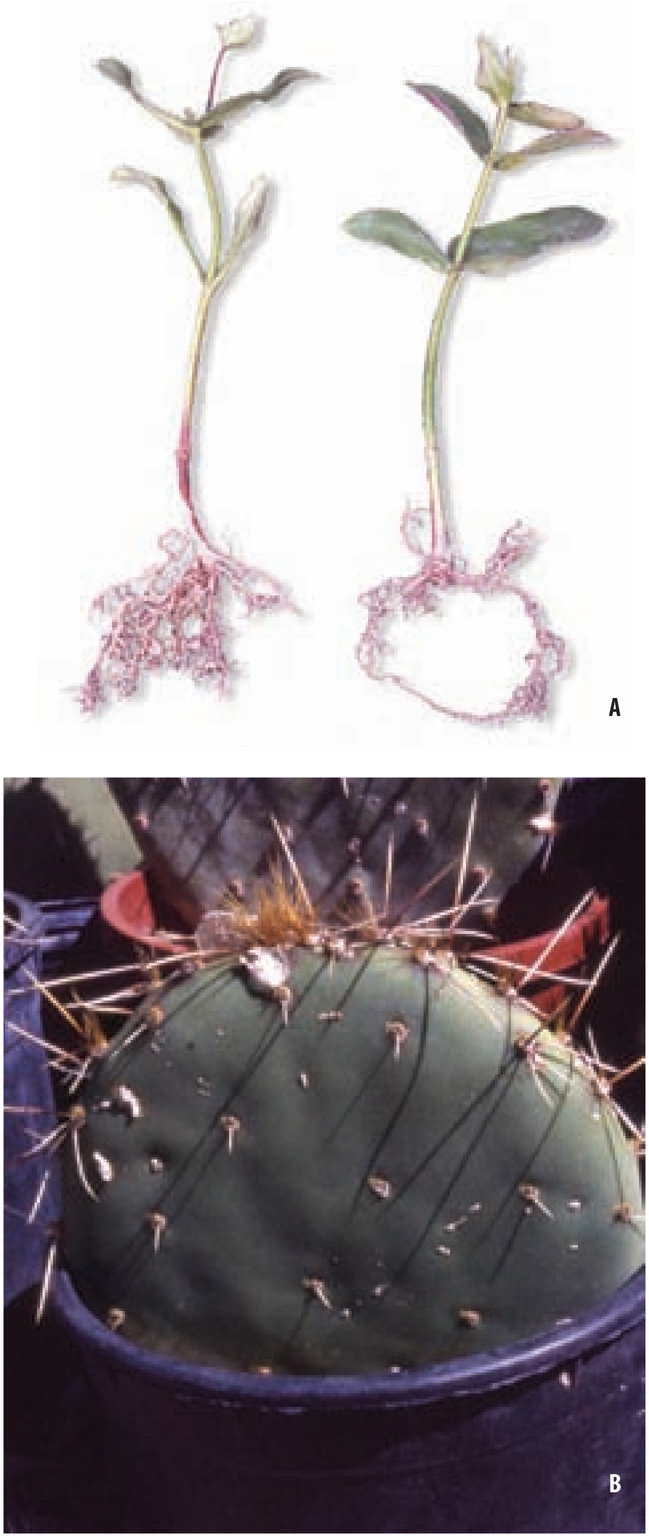

Figure 9.6—*Softwood duttings of many herbaceous native perennials, such as (A) Alberta pentsemon, can be easily rooted using mist and application of a rooting hormone. (B) Cacti cuttings must air- dry for several days before sticking into containers; unlike other cuttings, they do not need mist or high humidity to root.* Photos by Tara Luna.

Figure 9.7—*Semihardwood cuttings of Cascade mountain ash collected in late summer from a lateral branch with a maturing terminal bud.* Photo by Tara Luna.

Figure 9.8—*Root cuttings, such as these from quaking aspen, are used when stem cuttings do not root well.* Photo by Tara Luna.

al habit, whereas plants produced from terminal shoots will grow vertically. This habit can create problems with the growth habit of the nursery stock (figure 9.11).

Some species of plants are dioecious, meaning that male and female flowers are borne on separate plants. In such cases, collectors may not realize they have collected cuttings of only one sex. Outplanting plants of only one sex onto the restoration site may compromise project objectives because seed production over the long term would be impossible (Landis and others 2003). Therefore, be sure to collect both male and female cutting material (see Landis and others 2003).

The size and quality of the cutting are important. Cutting size varies from species to species and by seasonal timing. Easily rooted species such as willow can be collected as long poles for rooting or made into small microcuttings. Microcuttings consist of one bud and a small section of internode stem and are typically less than 2 in (5 cm) long (figure 9.12). Hardwood cuttings vary in length from 4 to 30 in (10 to 76 cm). At least two nodes are included in the cutting. The basal cut is made just below a node and the top cut is made above a node. If more than one cutting is being made from a stem, be certain that nursery workers handling the cuttings maintain the correct polarity. The very tip portions of the shoot, which are usually low in carbohydrates, are usually discarded. Central and basal portions of the stem cutting usually make the best cuttings, but there are exceptions. Good cutting wood has some stored carbohydrates that will supply the cutting with food reserves until roots form. Very thin or elongated shoots are not desirable. If cuttings are collected from natural stands, harvest from individuals that are growing in full sun to partial shade and avoid those in deep shade. Often, the ability of a cutting to produce new roots changes from the base of the cutting to the tip. Softwood stem cuttings are usually straight, 3 to 6 in (7.5 to 15 cm) long with two or more nodes. Generally, softwood cuttings root better from terminal shoots. Semihardwood cuttings are usually 3 to 6 in (7.5 to 15 cm) long with leaves retained in the upper end. Semihardwood cuttings usually root best from lateral shoots.

COMMON DIOECIOUS PLANTS

ash
buffaloberry
cottonwood
fourwing saltbush
joint fir
maple
silverberry
willow

Figure 9.9—*Cuttings should be collected only from healthy donor plants, such as these kinnikinnick, and preferably from juvenile wood.* Photo by Tara Luna.

Figure 9.10—*Hedging plants such as redosier dogwood on an annual basis provides many straight, juvenile woody shoots that can be used for cuttings.* Photo by Tara Luna.

Figure 9.11—*Plagiotropism is the effect of the position of the branch utilized for a cutting on the growth habit of the progeny. The terminal shoot on the juniper cutting on the right, collected as a lateral shoot, still exhibits lateral growth tendencies.* Photo by John Edson.

Figure 9.12—*Microcuttings are small one- to two-node cuttings that can be made from a single stem of willow.* Photo by Tara Luna.

Figure 9.13—*Equipment used for the collection of cuttings should include sharp tools, a cleaning agent for tools, and a cooler to keep cuttings from drying out during transport.* Photo by Tara Luna.

COLLECTING, TRANSPORTING, AND TEMPORARY STORAGE OF CUTTINGS

Some basic equipment and supplies are necessary to efficiently collect cuttings and ensure their health until they are used in the nursery (figure 9.13). The following items are recommended:

- High-quality, sharp pruning shears and pruning poles for collecting from trees.
- Spray bottles filled with disinfectant (1 part bleach (5.25 percent sodium hypochlorite) in 10 parts water) for pruning shears.
- Permanent labels and marking pens for noting origin of collection.
- Large, white plastic bags with ties for bulk collections.
- Spray bottles filled with water to keep cuttings moist in the plastic bags after collection.
- Portable, insulated coolers for transport back to the nursery.

When collecting and handling cuttings, it is important to:

- Collect only from healthy donor plants.
- Keep cuttings cool to avoid wilting and desiccation.
- Handle cuttings carefully so that tissues are not bruised.
- Make sure that some buds or leaves are present on stem cuttings.
- Collect from nonflowering shoots. In general, cuttings root better before or after flowering.
- Place cuttings in the same direction when bundling to avoid mix-ups with polarity during preparation back at the nursery.

Although hardwood cuttings collected during the dormant season are quite tolerant of handling and can be stored in refrigeration for weeks or months before striking (figure 9.14A), softwood and semihardwood cuttings should be collected during the early part of the day and storage should be kept to a minimum. Ideally, softwood and semihardwood cuttings are made on cloudy, cool days or during the early morning. All cuttings, even hardwood cuttings, should be handled with care to avoid water loss and physical damage. Techniques used for collecting and handling cuttings can

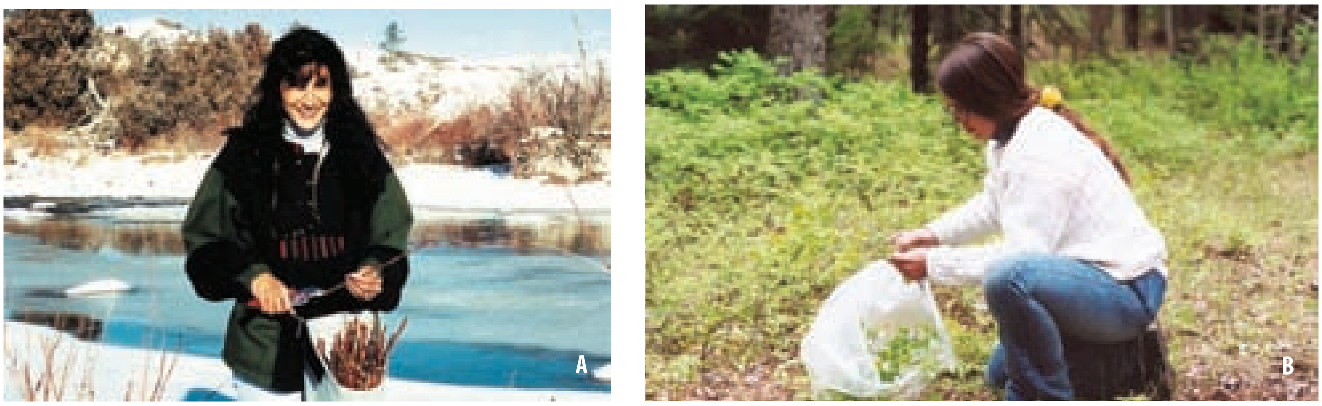

Figure 9.14—*Hardwood and softwood cuttings are handled very differently during collection: (A) hardwood cuttings can be collected during the dormant season and can be stored for several weeks in a cooler, (B) while softwood cuttings require more attention so that the stems and leaves do not wilt and desiccate before they are taken back to the nursery, and they are usually placed in the rooting chamber the same day of collection.* Photo A by Joyce Lapp, B by Tara Luna.

greatly affect rooting results. Cuttings should be kept cool and shaded during collection and transport back to the nursery. Never lay cuttings on the ground in full sun. Place cuttings into white plastic bags, mist them, and label with origin information and the date (figure 9.14B). When collecting from mother plants, make a proper cut that facilitates healing of the mother plant. Take the cutting just above a node, ensuring that you do not leave a stub. Then trim the base of the cutting to just below the node where rooting is more likely to occur. Between collection sites, disinfect the pruning shears with a solution of 1 part bleach (5.25 percent sodium hypochlorite) to 10 parts water to avoid the spread of disease.

At the nursery, refrigerated storage should be available to hold cuttings if they are not struck immediately. Deciduous hardwood cuttings can be stored for several days or weeks but generally no longer than 4 to 8 weeks. Wrap deciduous hardwood cuttings in moist peat moss or burlap before placing them into storage. Inspect stored cuttings frequently to make certain that tissues are slightly moist and free from fungal diseases. Hardwood and softwood evergreen cuttings, deciduous softwood cuttings and semihardwood cuttings should not be stored for longer than 1 day and preferably should be struck in propagation beds the same day of collection.

TYPES OF ROOTING AND PROPAGATION ENVIRONMENTS

The development of new roots on a shoot is known as "adventitious root formation." Two types of roots occur depending on whether buds capable of producing new roots are present. If buds are present, the resulting roots are termed "preformed" or "latent." Native species such as willow and cottonwood have preformed or latent root initials. In the nursery, cuttings of these species are usually struck directly into containers because they do not require a special rooting environment. This method is the easiest and most economical way to produce these species because no additional transplanting is needed.

If no buds are present, then the roots are termed "wound-induced" and new roots form only in response to the wound caused by preparing the cutting (figure 9.15A). Species requiring wounds can vary considerably in their ability to form new roots. After a root is wounded, callus tissue forms at the base of a cutting, primarily from the vascular tissue (figure 9.15B), but callus formation is not always essential to rooting. In easy-to-root species, callus formation and root formation are independent processes that occur at the same time because of similar environmental triggers (figures 9.15B and C). In difficult-to-root species, adventitious roots arise from the callus mass. In some cases, excessive callus can hinder rooting and is a signal to use a lower concentration of rooting hormone. Often, excess callus should be scraped away and the cutting replaced in the rooting environment.

In general, all species with wound-induced roots must first be rooted in a special propagation environment in which the temperature of air and medium are tightly controlled. High relative humidity is encouraged, light levels are often reduced, and the medium is kept "moist but not wet." See Chapter 4, *Propagation*

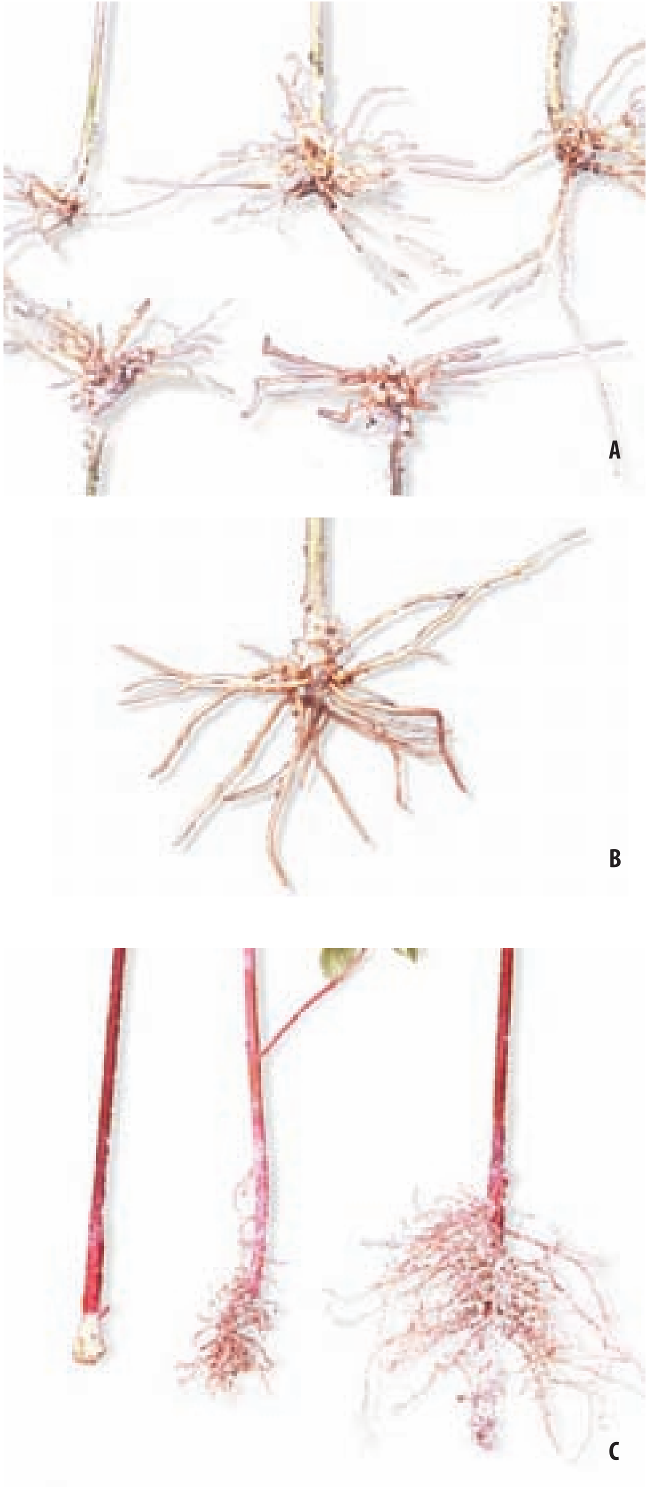

Figure 9.15—*(A) Note adventitious roots of a cutting, (B) callus and roots forming at the base of a cutting, and (C) the development of adventitious roots over a 6-week period.* Photos by Tara Luna.

Figure 9.16—*Developing an efficient system for producing cuttings, employing experienced propagators, and keeping the work area clean are key aspects to reducing production costs.* Photo by William Pink.

Environments, for more details on propagation environments. Easy-to-root species are often struck directly into containers filled with regular growing medium and, once rooted in the special propagation environment, are moved into the regular nursery. Hard-to-root species are often struck into a special rooting medium and, after roots form, are transplanted into containers to continue their growth.

Cutting Preparation

While preparing cuttings, it is important to keep the work area clean (figure 9.16). Use sharp, well-maintained shears and knives to make clean cuts and disinfect them often to reduce the possible spread of disease. Preparing cuttings standardizes their size and shape, promotes side shoots, and eliminates shoot tips that often die back. It is important to maintain polarity during this process, especially for deciduous hardwood cuttings. Cuttings that will require hormone treatment to encourage rooting, such as those of hardwood narrowleaf evergreens or any softwood or semihardwood cuttings, should have one-third to one-half of the leaves and buds removed to reduce the amount of water loss from the cutting. Any flower buds should also be removed. It is important, however, to retain some buds or leaves on the cutting so that the cutting can manufacture food during rooting.

Figure 9.17—*Wounding the lower end of the stem often increases rooting results and root mass, especially on cuttings that are difficult to root.* Photo by Tara Luna.

Figure 9.18—*Willow water solution is a homemade rooting hormone that can be used on easy-to-root species.* Photo by Tara Luna.

Wounding Cuttings

Wounding, used on species that are difficult to root, increases rooting percentages and improves the quantity and quality of roots produced. Wounding exposes more cells to rooting hormone, encourages callus formation, and, in some cases, removes thick woody tissue that can be a barrier to root formation (figure 9.17). Cuttings are commonly wounded by hand-stripping small lower stems and leaves to create wounded areas along the basal portion of the cutting, scraping the base of the stem with a small, sharp knife or potato peeler (figure 9.17), or slicing one or two long, shallow slivers (0.75 in to 1.25 in [2 to 3.2 cm] long) of tissue from the base of the stem, making sure to penetrate the cambium layer of the stem. Slicing requires precision and experience so that cuttings are not excessively damaged.

Rooting Hormones

Auxins are natural plant hormones that encourage root formation on cuttings and are available from natural and synthetic sources. In practice, auxins are commonly referred to as rooting hormones. Willows are a natural source of auxins (Leclerc and Chong 1984). "Willow water" is a rooting hormone solution that can be made by cutting green, actively growing willow stems into 1-in (2.5-cm) pieces, mashing them, placing them in water brought to a boil, and then removing them from the heat to cool and steep overnight. After removing the willow stems, cuttings can be soaked overnight in the willow water and then planted (figure 9.18).

Most cuttings, however, are treated with synthetic hormones that are available in powder and liquid form, and some preparations may contain chemical fungicides (figure 9.19). Synthetic hormones can be purchased ready to use or can be mixed by growers to specific concentrations. Indole-3-butyric acid (IBA) and naphthaleneacidic acid (NAA) are the most widely used synthetic auxins for rooting. Often, mixtures of IBA and NAA are more effective than either component alone. The effect of rooting hormones varies widely between species and, in some cases, between genotypes. The concentration of a rooting hormone is expressed in either parts per million (ppm) or as a percentage. In general, rooting hormone powders are expressed as a percentage, while liquid solutions are expressed as ppm.

Although nursery workers can either purchase synthetic rooting hormones in liquid or powder forms or prepare their own from ingredients purchased from horticultural suppliers, it is generally easiest to purchase ready-to-use formulations. It is important to remember that all rooting hormones have a limited shelf life of 18 to 24 months. Therefore, when purchasing or mixing hormones:

Figure 9.19—*Advantages of using rooting hormones on cuttings include (1) increased overall rooting percentages if applied correctly and at an effective concentration, (2) more rapid root initiation, (3) an increase in the total number and quality of roots, and (4) more uniform rooting.* Photo by Tara Luna.

Figure 9.20—*Although powders are preferred to liquid hormones by many growers, care should be taken to apply powder hormones evenly and consistently.* Photo by Tara Luna.

- Record the date of purchase on the container.
- Order only what you plan to use within 18 to 24 months. Order smaller quantities more often to ensure that the rooting hormone remains effective.
- Keep containers sealed and refrigerated when not in use to preserve the activity of the root hormone.
- Always pour a little into a separate container when treating cuttings.

Many growers prefer powders because a number of prepared commercial products of varying strengths are available, they are easy to use, and large quantities of cuttings can be treated quickly.

However, powder must be applied uniformly to all cuttings; variable amounts of rooting powder adhere to the base of a cutting, which can affect rooting results (figure 9.20). The following precautions and special techniques are needed when using powders:

- Wear gloves during application.
- Transfer enough hormone to a smaller container from the main stock container for use. Never transfer unused hormone back to main stock container.
- Apply the hormone uniformly; make sure the base of the cutting is moist so that the powder adheres. Pressing cuttings lightly onto a moist sponge is a good idea.
- Ensure cuttings are dipped into the powder to a depth of 0.2 to 0.4 in (5 to 10 mm). Make certain that cut surfaces and other wounds are also covered with rooting hormone.
- Remove excess powder by lightly tapping the cuttings on the side of the dish.

Liquid products are formulated with alcohols and often must be diluted with great care to the desired strength. Some of the advantages of using solutions are a wide range of commercial preparations is available, specific concentrations can be formulated at the nursery, and they can be stored for longer periods under the right conditions. Some growers believe that using solutions is more accurate than powders are in regard to the amount of rooting hormone entering the stem tissue. The most common procedure for treating cuttings is using the concentrated-solution-dip method (quick-dip method) in which the base of the cutting is dipped into the solution for 3 to 10 seconds. Whole bundles of cuttings can be treated at once (figure 9.21). Alternately, cuttings can be soaked for a longer period of time in a more dilute hormone solution. When using liquid rooting hormones, it is important to:

Figure 9.21—*Using the liquid hormone "quick dip" method is preferred by many growers because bundles of cuttings can be treated at the same time with a consistent uniformity of application.* Photo by Tara Luna.

- Wear gloves during mixing, preparation, and application.
- Make certain that the solution was diluted to the right concentration correctly and precisely.
- Place the solution in a clean jar.
- Ensure that the treatment time is constant for a uniform application rate and to avoid damaging the plant tissue (phytotoxicity).
- Make certain that the basal ends are even to obtain uniform depth of dipping in the solution if bundles of cuttings are dipped.
- Allow the alcohol to evaporate from the stem of the cutting before striking cuttings into the propagation bed, a process that usually takes only a couple of minutes.
- Properly discard any remaining solution, because it is contaminated with plant material.

STRIKING, MONITORING, AND GROWING CUTTINGS

As mentioned previously, cuttings may be struck directly into containers or struck into special rooting environments. Direct striking into containers is more efficient and therefore more economical than striking into a special rooting environment because the cuttings are handled only once and expensive transplanting is avoided. Easy-to-root hardwood cuttings, such as those from redosier dogwood, willow, and cottonwood (figure 9.22), should always be direct struck. Often, a dibble of the same diameter and depth of the stem of the cutting is a useful tool for making openings in the medium into which the cutting can be struck. If using powdered rooting hormones, this practice will help keep the hormone from being brushed off. The following should be encouraged when striking cuttings:

- Wear gloves if the cuttings were treated with rooting hormones.
- Maintain polarity (keep the correct end of the cutting up).
- When using stem cuttings, make certain that at least two nodes are below the surface of the rooting medium.
- If cuttings were wounded, make certain that wounded tissue is adequately covered with rooting hormone and is below the surface of the rooting medium.
- Strike cuttings firmly in the rooting medium. Make certain to avoid air pockets around the base of the stem.
- Try to strike cuttings within 1 to 2 days so that all the plants will have the same level of root development and thus can be hardened off properly prior to lifting.

After cuttings are struck, maintain a clean rooting environment (figure 9.23); routinely inspect cuttings for proper temperature, humidity, and moisture levels and adjust as necessary to match daily weather conditions. Check to ensure that all equipment (including bottom heat) is working properly.

Environmental Conditions for Direct Struck Cuttings

In general, easy-to-root hardwood cuttings directly struck into containers can be treated similar to seedlings. Details on growing container seedlings are presented in chapters 10 through 13.

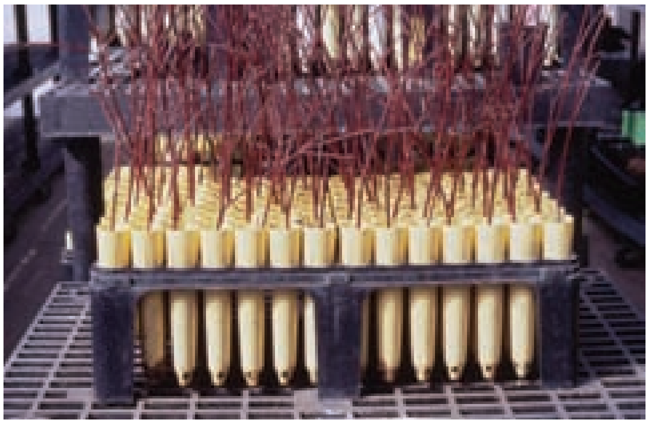

Figure 9.22—*Easy-to-root hardwood cuttings can be directly struck in containers; this is the most economical way of producing cuttings.* Photo by Tara Luna.

Figure 9.23—*The propagation environment must be carefully monitored to ensure that the mist system, the timers that control the frequency of mist, bottom heat, and other equipment are working properly. Equipment controls for outdoor mist systems need to be adjusted to accommodate daily changes in wind, temperature, and rain.* Photo by Tara Luna.

Environmental Conditions in Special Rooting Environments

Achieving successful rooting requires attention to sanitation, relative humidity, temperature, light, rooting medium, and sometimes mycorrhizae and mineral nutrition. See Chapter 4, *Propagation Environments,* for information about equipment necessary to regulate humidity, temperature, and light.

Sanitation

Always keep the propagation environment as clean as possible. Strike cuttings into a sterilized rooting medium. Routinely inspect for and remove dead leaves or cuttings that could be a source of disease infection.

Humidity

Until the root system forms, high levels of relative humidity must be provided to slow the rate of water loss from the cutting.

Temperature

The optimum air temperature for rooting cuttings is 65 to 75 °F (19 to 24 °C). The rooting medium temperature should be 10° F (5.5 °C) higher than the air temperature; this heat is generated by bottom heating cables beneath the rooting media or flats.

Light

Providing light for photosynthesis is necessary so that cuttings can continue to manufacture food during rooting, but too much sunlight can cause excessive air temperatures. Shadecloths of 30 to 50 percent shade cover are most effective to reduce air temperature while providing sufficient light.

Rooting Medium

A good rooting medium provides aeration and moisture and physically supports the cuttings. A pH of 5.5 to 6.5 is optimum for most plants, but acid-loving plants prefer 4.0 to 5.0. Some common components of rooting media generally include a combination of two or more of the following: large-grade perlite, pumice, *Sphagnum* peat moss, sawdust, sand, and fine bark chips.

Different combinations of the components are used depending on the species being propagated. Selection of the rooting medium components influences rooting percentages and the quality of roots produced. Using very fine- or very coarse-grade sands tends to discourage the development of secondary roots. Roots that do form tend to be brittle and break off during the process of transplanting the cuttings into containers for further plant development. A good rooting medium promotes the development of fibrous root systems that retain rooting medium during transplanting, which reduces "transplant shock."

Mycorrhizal Fungi

Some growers inoculate the rooting medium with mycorrhizal fungi or other symbiotic organisms, which has improved rooting results with some plants (Scagel and others 2003). This practice may be especially important for those species that take a long time to form roots, such as Pacific yew, blueberries, cranberries, and rhododendrons. See Chapter 14, *Beneficial Microorganisms*, for more information on mycorrhizae.

Nutrient Mist

Some difficult-to-root cuttings may remain in a special rooting environment for a long period of time. Over time, the cuttings can become weakened, resulting in yellowing of the leaves or leaf and needle drop. Nutrients can be leached from the leaves by the long exposure to overhead misting. In these cases, the application of a dilute, complete foliar fertilizer through the mist line can improve cutting vigor and may aid in rooting. Because some species respond favorably to nutrient mist while others are adversely affected, you will need to do some preliminary trials before treating all the cuttings.

Transplanting Cuttings from Special Rooting Environments

A few weeks after striking cuttings into the rooting environment, they should be inspected for root development. Using a trowel, carefully lift a few cuttings by digging well below the end of the cutting. After most cuttings have initiated roots, turn off the bottom heat to encourage the development of secondary roots. When cuttings have developed adequate root systems, they need to be hardened for life outside the rooting environment. See Chapter 12, *Hardening*, for more information. The goal is to condition stem and leaf tissues and promote secondary root development before transplanting. Cuttings can be hardened by following these guidelines:

- Gradually reduce the misting frequency over a period of 3 to 4 weeks.
- Increase the frequency and duration of ventilation in enclosed propagation systems.
- Do not let the rooting medium dry out completely.

After cuttings have hardened, transplant them into containers and transfer them to the nursery for additional growth. Because cuttings are more expensive to produce than seedlings, it is important to handle them carefully at this stage (figure 9.24). It is essential to avoid root damage by following these guidelines:

- Examine each cutting to ensure it has a sufficient root system capable of sustaining the cutting after transplanting. Cuttings with only a few slender roots or very short roots should remain in the propagation bed for further root development (figure 9.24A.)
- Transplant only on cool, overcast days or during early morning hours to avoid transplant shock.
- Transplant cuttings in an area of the nursery protected from wind and sunlight.
- Prepare containers, medium, labels, and transplanting tools before removing cuttings from the rooting medium.
- Moisten the growing media prior to transplanting to prevent tender roots from drying out.
- Remove cuttings from the rooting medium carefully and remove only a few at a time so roots will not dry out. Loosely wrap a moist paper towel around the root systems until they are transplanted.
- Handle cuttings carefully by holding the cutting by the stem and by leaving any rooting medium still attached to the root mass. Do not shake medium off the root system.
- Partially fill the container with moistened medium before inserting the cutting. Then add additional moistened medium and gently firm the medium with fingers without breaking the roots (figure 9.24B).
- Do not transplant the cuttings too deep or too shallow.

After transplanting the cuttings, they should be placed in a shadehouse or protected from full sun and wind for at least 2 weeks. When the cuttings appear to be well established, gradually increase the level of sunlight by moving them to a different area of the nursery or by exchanging the shadecloth for one with a more open weave. After a couple of weeks, move the sun-requiring species into full sun. Cuttings should be closely monitored for any sign of stress. Adequate sunlight is needed for new shoot growth and adequate accumulation of carbohydrates prior to winter. Cuttings should put on as much growth as possible to minimize winter mortality.

OVERWINTERING CUTTINGS

Sometimes cuttings will not have a sufficient root mass for transplanting by the end of summer. In this case, they should be left undisturbed and transplanted the following spring. Be sure to begin hardening them at least 6 weeks before the first frost. See Chapter 12, *Hardening,* for procedures. Newly rooted cuttings need extra protection during overwinter storage. Ideally, the root temperature should be kept at 34 to 41 °F (1 to 5 °C).

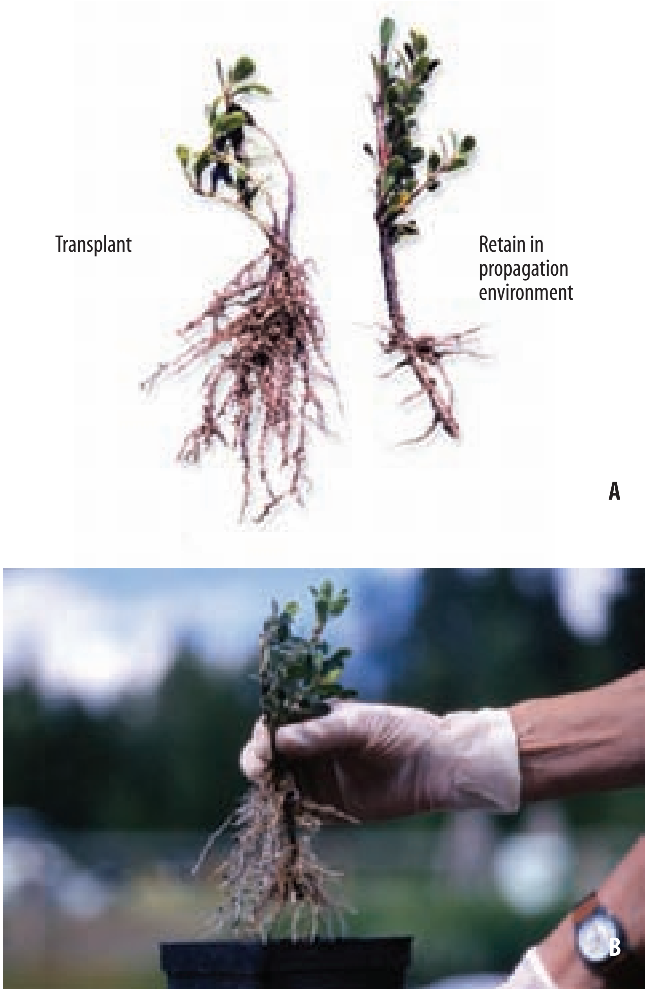

Figure 9.24—*(A) Cuttings should have enough developed roots to support the cutting once it is lifted and planted outside the mist system. Cuttings with underdeveloped roots should be left in the propagation environment longer to develop an adequate root mass. (B) Cuttings should be handled carefully during lifting and potting by keeping the tender roots undamaged and moist.* Photos by Tara Luna.

Figure 9.25— *Many native plants, such as antelope bitterbrush on the Hopi Reservation, will layer naturally when lower branches come in contact with the soil.* Photo by Tara Luna.

The medium surface can freeze but not to a depth that injures young roots. Loss of cuttings due to improper overwintering storage is a common occurrence and contributes significantly to costs. For a full discussion on overwintering plants, including cuttings, see Chapter 13, *Harvesting, Storing, and Shipping*.

OTHER METHODS OF VEGETATIVE PROPAGATION

Besides stems and roots, several other portions of mother plants can be used to vegetatively propagate new daughters, and stems can be used in ways other than the traditional cutting described previously.

Layering

Layering is a technique by which adventitious roots are formed on a stem while still attached to the plant. Layering often occurs naturally without the assistance of a propagator (figure 9.25). It is mostly used by nurseries with a long growing season and on those species that fail to root from stem or root cuttings. Layering is started when plants are dormant. Four types of layering can be used by propagators: simple, French, mound, and drop. **Simple layering** is used on species that produce many shoots annually. Long, low-growing flexible shoots are pegged down 6 to 9 in (15 to 23 cm) from the shoot tip, forming a “U” (figure 9.26A). The bottom of the U stem is girdled with a sharp knife and is covered with soil or sawdust, leaving the tip exposed. After a sufficient root system is formed, the new plant can be severed from the donor plant (figure 9.26B). **French layering** is similar to simple layering but uses a long, single branch that is pegged down to the soil surface. The following spring, pegs are removed and the branch is laid into a trench and buried up to the tips of the shoots with well-aerated soil (figure 9.27A) and sawdust or mulch (figure 9.27B). After burying repeatedly, each shoot along the stem will form roots by autumn of the second year. **Mound layering** or stooling involves selecting a young stock plant (figures 9.28A and B) and cutting back shoots to a couple of inches above ground level (figure 9.28C). Numerous shoots develop in consecutive growing seasons and are covered to half their height with sawdust (figure 9.28D). This procedure is repeated three times as the shoots grow so that, by the end of the second or third growing season, the well-rooted shoots are unburied and are ready to plant as individuals (figures 9.28E and F). **Drop**

layering is very similar to mounding. Drop layering involves planting well-branched container plants deeply in the ground with only the tips of the branches exposed. New growth forms from the exposed branch tips, but the buried portions of the stems form roots along the stems.

Stacked layering is a new vegetative propagation method for quaking aspen and other rhizomatous species (Landis and others 2006). This technique takes advantage of the rapid and extensive root growth of seedlings and the fact that severed roots will form new shoots. In the spring, a stack of Styrofoam™ containers is created with a 1-gallon pot containing a seedling inserted in the top block. The lower Styrofoam™ containers are filled with growing medium with a thin layer of medium sandwiched between the blocks (figure 9.29A). By next spring, the roots of the mother plant will have grown down through and colonized the cavities in the lower blocks. Running a sharp knife between the Styrofoam™ containers severs the roots, which then form new shoots (figure 9.29B). After a few months, the new plants can be transplanted into larger pots. Another set of filled Styrofoam™ containers can be situated below the block with the mother plant to start another propagation cycle. Stacked layering is ideal for propagating species where seeds are rare or other vegetative techniques will not work.

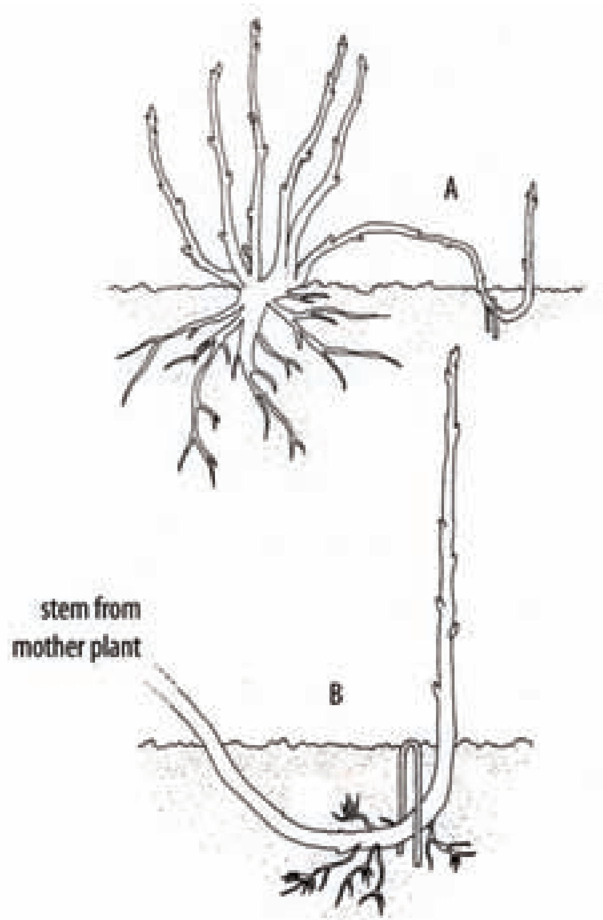

Figure 9.26—*Simple layering.* Illustration by Bruce McDonald and Timber Press Inc.

Bulbs, Corms, Tubers, Rhizomes, and Crown Division

Bulbs, tubers, corms, and rhizomes are specialized plant structures that function in the storage of food, nutrients, and water. Many culturally important native species not easily grown from seeds have these structures.

A *bulb* is an underground storage organ consisting of a short, fleshy stem surrounded by fleshy modified leaves (scales). Tunicate and scaly are two types of bulbs. Tunicate bulbs have outer scales that are dry and membranous (figure 9.30A). Tunicate bulbs can be propagated by using offsets, scoring, scooping, coring, sectioning, and cuttage. **Offsets** of tunicate bulbs are the main method used to increase bulb stock. Any species that readily produces offsets can be propagated this way, but a large amount of bulbs is required to produce many plants (figure 9.30B). Camas and mariposa lily may be propagated by offsets. **Basal scoring** is when three incisions are made at the base of the bulb, deep enough to go through the basal plate and the growing point. Growing points in the axils of the scales grow into bulblets. The bulbs can be placed in a warm, dark place at high humidity for a few months or planted upside-down (basal plate up) in clean dry sand, vermiculite, or perlite. Basal scooping is the removal of the entire basal plate to remove the shoot and flower bud at the center of the bulb. This exposes the fleshy leaf bases from which small bulblets will develop. **Coring** involves removal of the center portion of the basal plate and the main growing point of the bulb. Cored bulbs can be treated as described for scoring. **Sectioning** involves cutting a mature bulb into five to ten pie-shaped sections, each with a portion of the basal plate attached. These sections are treated and handled as described for scoring. **Cuttage** involves cutting a mature bulb vertically into six or eight sections. Next, the basal plate is cut so there are one to four scale segments attached on each piece of basal plate. These are treated with a fungicide and planted in perlite or vermiculite with the segment tips exposed above the rooting medium.

Scaly bulbs (also known as nontunicate bulbs) lack a tunic and are characterized by the scales being sepa-

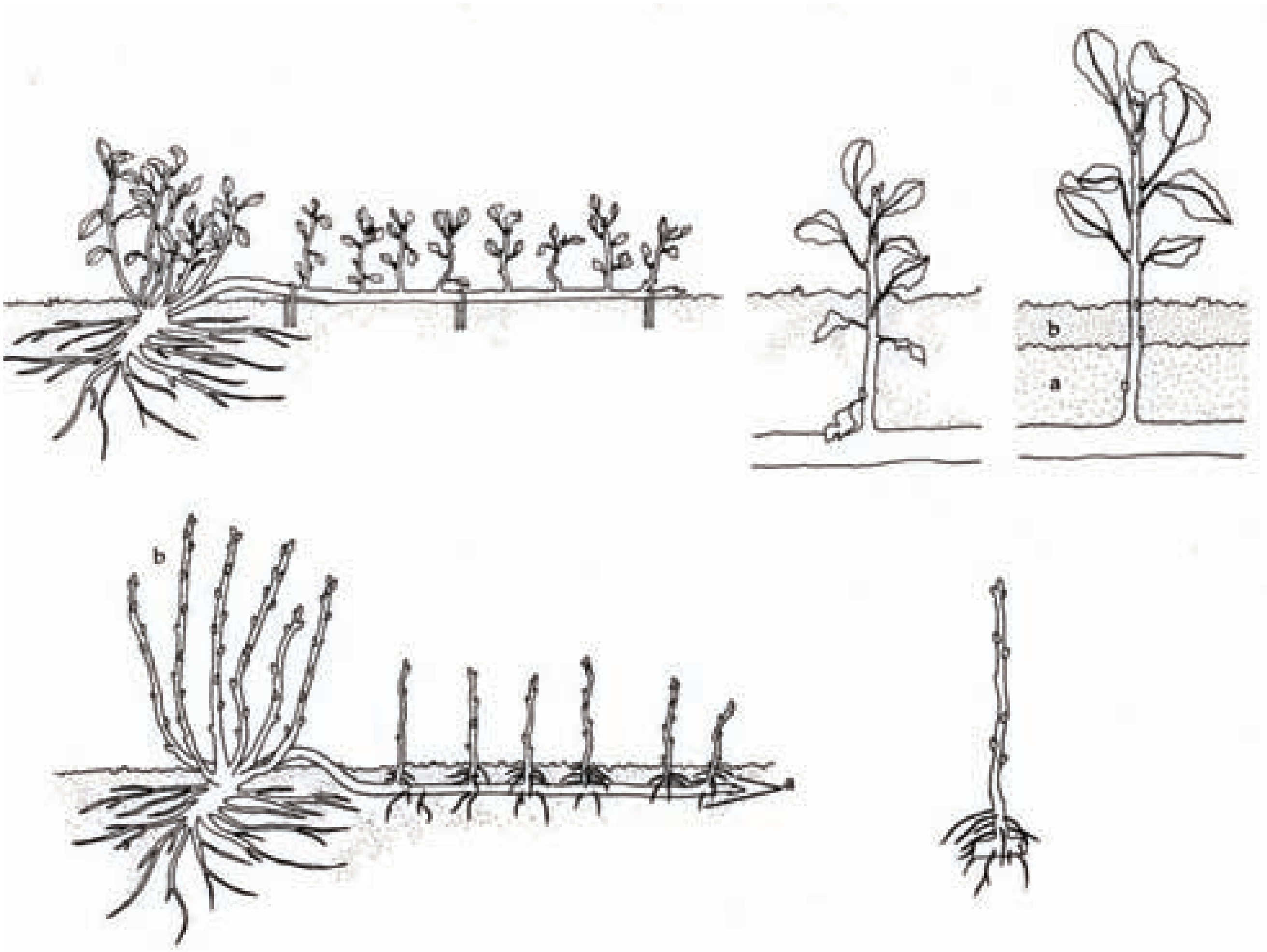

Figure 9.27— *French layering.* Illustration by Bruce McDonald and Timber Press, Inc.

rate and attached to the basal plate (figure 9.31). They are easily damaged and will dry out quickly without the protective tunic, so it is necessary to handle them with more care. These bulbs are propagated by scaling, which is done after flowering. The outer two layers of scales are removed from the mother bulb and treated with rooting hormone to induce bulblet formation. Scales are inserted vertically (about half their length) in propagation flats with moist sand and peat moss. Two or three growing seasons are needed to reach flowering size. Individual bulb scales are removed from the mother bulb and placed in growing conditions so that bulblets form at the base of each scale. Usually, three to five bulblets form per scale. Native lilies and fritillaries are propagated by scaling.

A *corm* is very similar to a tunicate bulb and consists of a swollen stem base enclosed by the dry, scale-like leaves (figure 9.32). It differs from a bulb in being a solid stem structure consisting of nodes and internodes that are compressed. Cormels are miniature corms that form between the old and new corms. One to 2 years of growth is usually required for them to reach flowering size. Trout lilies and some shooting stars produce corms.

Tubers are swollen modified stems that serve as underground storage organs. The most common tuber is the potato. "Eyes" are actually nodes containing buds. Propagation by tubers involves planting the entire tuber or dividing it into sections containing at least one eye or bud. Wapato is a native plant that produces tubers.

Rhizomes are specialized stems in which the main axis of the plant grows horizontally or vertically at or below the soil surface. Many native species, such as iris, repro-

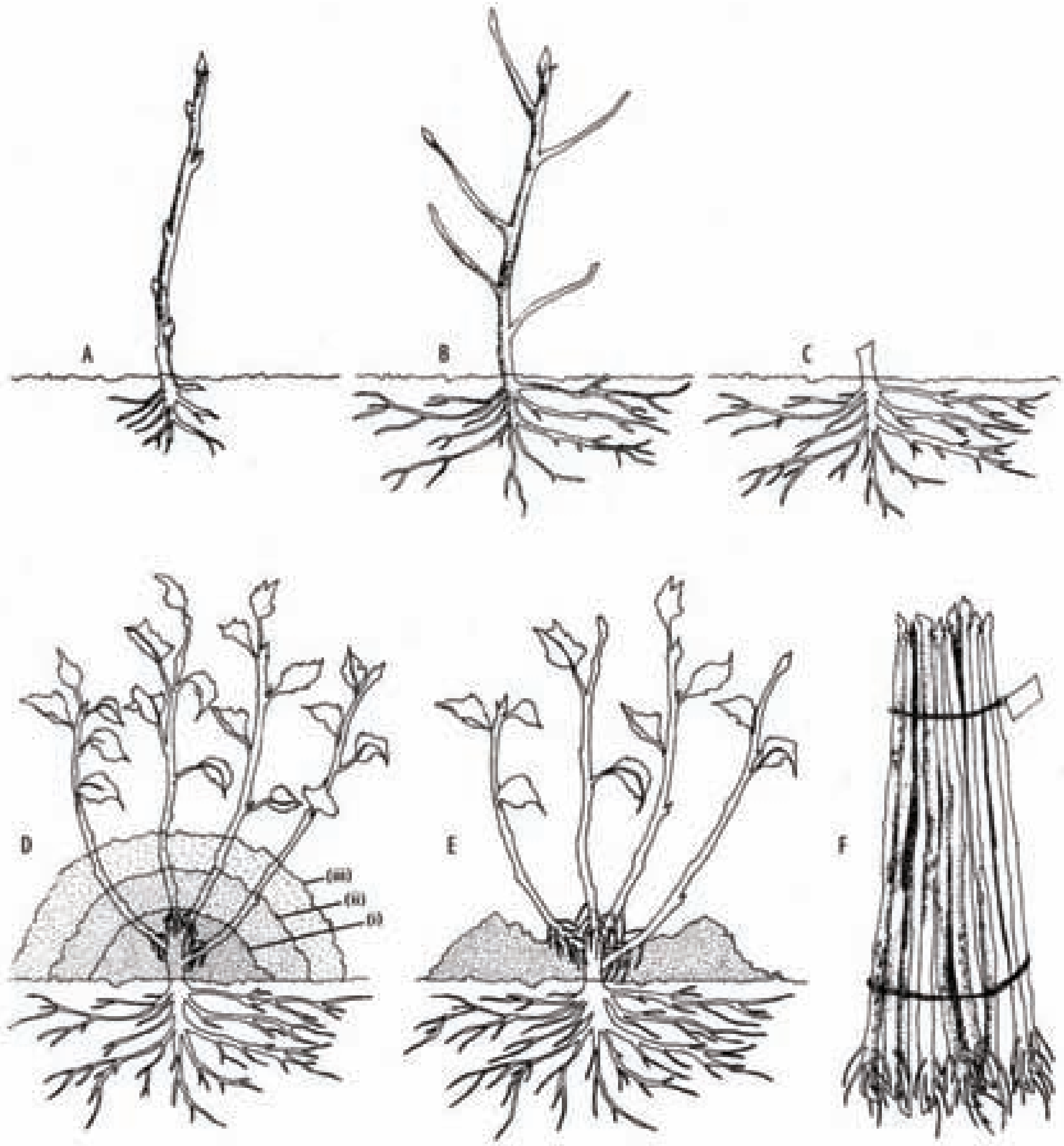

Figure 2.28—*Mound layering.* Illustration by Bruce McDonald and Timber Press, Inc.

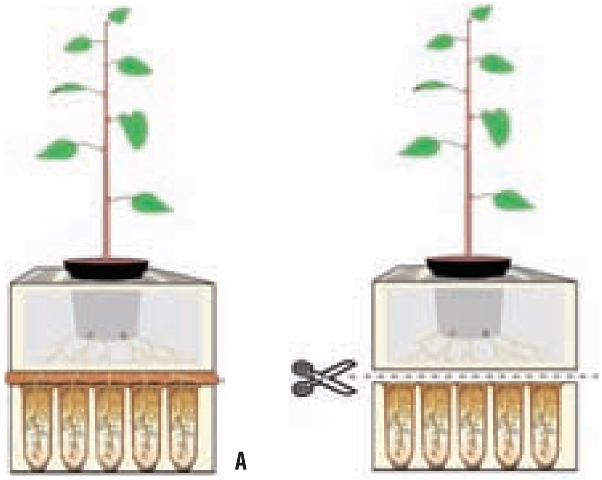

Figure 9.29—*(A) Roots from the mother plant grow downward through the cavities of stacked Styrofoam™ containers. (B) The roots are then severed, after which they develop new shoots.* Illustration by Jim Marin.

Figure 9.30—*(A) Camas is a native cultural plant with a tunicate bulb. (B) Native bulbs are often grown in raised beds; offsets from the mother bulbs are harvested and planted when they are dormant.* Photos by Tara Luna.

duce by rhizomes and they are easily propagated into larger numbers from a few nursery plants by divisions (figure 9.33).

Rhizomes vary in length and size according to species. Rhizomes are cut into sections with each containing at least one shoot bud or active shoot; some roots are attached to the bottoms of the rhizomes and are planted into containers individually. Rhizomes can also be planted in nursery beds and used as a source for bareroot stock for planting or for cultural uses such as basketry (figure 9.34).

Another method of propagation by division that differs slightly from dividing rhizomes is crown division. It is an important method for propagating many native herbaceous perennials that produce multiple offshoots from the crown. Crown divisions are usually done in early spring just before growth begins (species that flower and grow in spring and summer) or in late summer (species that bloom in late summer and early autumn). Plants are dug up and cut into sections with a sharp knife, each with a substantial portion of the root system, and transplanted individually.

Stolons, Runners, and Offsets

Stolons, runners, and offsets are specialized plant structures that facilitate propagation by layering. Stolons are modified stems that grow horizontally above the soil line and produce a mass of stems (figure 9.35A). Runners are specialized stems that arise from the crown of the plant and grow horizontally along the ground and produce a plantlet at one of the nodes (figure 9.35B). Raised beds planted with species with stolons or runners can be an endless source of material, and plants can be dug and potted individually or transplanted as bareroot stock.

Plants with rosettes often reproduce by forming new shoots, called offsets, at the base of the main stem or in the leaf axils. Offsets are cut close to the main stem of the plant with a sharp knife. If well rooted, an offset can be potted individually. Sever the new shoots from the mother plant after they have developed their own root systems. Nonrooted offsets of some species may be removed and placed in a rooting medium. Some of these offsets must be cut off, while others may simply be lifted from the parent stem.

Micropropagation

Micropropagation is a process used to propagate plants using very specialized tissue culture techniques. Tissue culture is the procedure for maintaining and growing plant tissues and organs in an aseptic culture in which the environment, nutrient, and hormone levels are tightly controlled. A small piece of vegetative material called the explant is used to create a new, entire plant. Rare or greatly endangered native species have been micropropagated to increase the number of individuals for restoration projects when other methods of propagation have been limiting or failed. Micropropagation has also been used as a method to offer plants in the nursery trade in order to preserve them from poaching and eventual extirpation from wild populations. Micropropagation works well for some species and poorly for others. For some native plants, such as orchids, it is one of the only options for successfully germinating seeds. Most native plant nurseries do not have an elaborate tissue culture facility because of the high cost, although small-scale micropropagation can be done with minimal equipment in a clean room. Micropropagation continues to play a role in the conservation of native plants and is included here as a viable propagation option when other methods fail. See volume 2 of this handbook for species that have been micropropagated.

ESTABLISHING MOTHER PLANTS AT THE NURSERY

Some nursery managers find it advantageous to maintain donor plants at the nursery as a continual source of cutting material. This practice can be more efficient than collecting from wild populations year after year, especially if the same ecotypes will be used for a long-term restoration project. Usually, mother plants are planted in field beds at the nursery or, in some cases, are kept in large containers. Regardless, mother plants must be clearly labeled as to species and origin. If mother plants are in field beds, an accurate map should be kept. Mother plants should be hedged on an annual basis to maintain wood juvenility and to produce numerous straight shoots to use as cutting material. One disadvantage to using mother plants grown at the nursery is that they require nursery space and must be intensively managed.

Figure 9.31—*Cormels form between the old and new corms and can be separated and planted individually.* Photo by Tara Luna.

Figure 9.32—*Scaly bulbs, such as those of yellowbells, can be propagated by (A) scaling and by (B) removing and planting the small rice-like bulblets individually.* Photos by Tara Luna.

Figure 9.33—*Many native plants have rhizomes. Rhizomes vary in thickness and length and can be used to propagate many more plants from existing nursery stock. (A) Missouri iris and (B) and (C) water sedge propagated from divisions.* Photo A by Tara Luna, B and C by Thomas D. Landis.

Figure 9.34—*(A) Dogbane rhizomes can be raised in field beds for cultural uses such as basketry. (B) White-rooted sedge being raised in field beds for basketry.* Photo A by William Pink, B by Chuck Williams.

SUMMARY

Vegetative propagation is the production of daughter plants from the stems, leaves, roots, or other portions of a single mother (donor) plant. Daughter plants contain the exact genetic characteristics of the donor. Vegetative propagation techniques can be used on many species if seeds are unavailable or difficult to germinate. Producing plants from cuttings is more labor intensive and expensive, and production may require special propagation structures. Experience is required to determine the best collection time, hormone treatment, and medium necessary to root cuttings. Some native species cannot be successfully rooted from stem cuttings, while others can be propagated from root cuttings, divisions, or layering. Micropropagation is an option for propagating rare and endangered species or others that are very difficult to propagate by other methods. Keeping good records will improve the success of rooting cuttings and reduce nursery costs.

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APPENDIX 9A. PLANTS MENTIONED IN THIS CHAPTER

Alberta penstemon, *Penstemon albertinus*
antelope bitterbrush, *Purshia tridentata*
ash, *Fraxinus* species
blueberry, *Vaccinium* species
buffaloberry, *Shepherdia* species
camas, *Camassia quamash*
cascade mountain-ash, *Sorbus scopulina*
cottonwood, *Populus* species
cranberry, *Vaccinium macrocarpon*
dogbane, *Apocynum cannabinum*
fourwing saltbush, *Atriplex canescens*
fritillary, *Fritillaria* species
jointfir, *Ephedra* species
juniper, *Juniperus* species
kinnikinnick, *Arctostaphylos uva-ursi*
lily, *Lilium* species
maple, *Acer* species
mariposa lily, *Calochortus* species
Missouri iris, *Iris missouriensis*
Pacific yew, *Taxus brevifolia*
quaking aspen, *Populus tremuloides*
redosier dogwood, *Cornus sericea*
rhododendron, *Rhododendron* species
silverberry, *Elaeagnus commutata*
shooting star, *Dodecatheon* species
snowberry, *Symphoricarpos albus*
trout lily, *Erythronium* species
twinflower, *Linnaea borealis*
wapato, *Sagittaria latifolia*
white-rooted sedge, *Carex barbarae*
wild strawberry, *Fragaria* species
willow, *Salix* species
yellowbells, *Fritillaria pudica*

Figure 9.35—*(A) Stolons of twinflower and (B) runners of wild strawberry can be collected and used to root several plants from one plant.* Photos by Tara Luna.