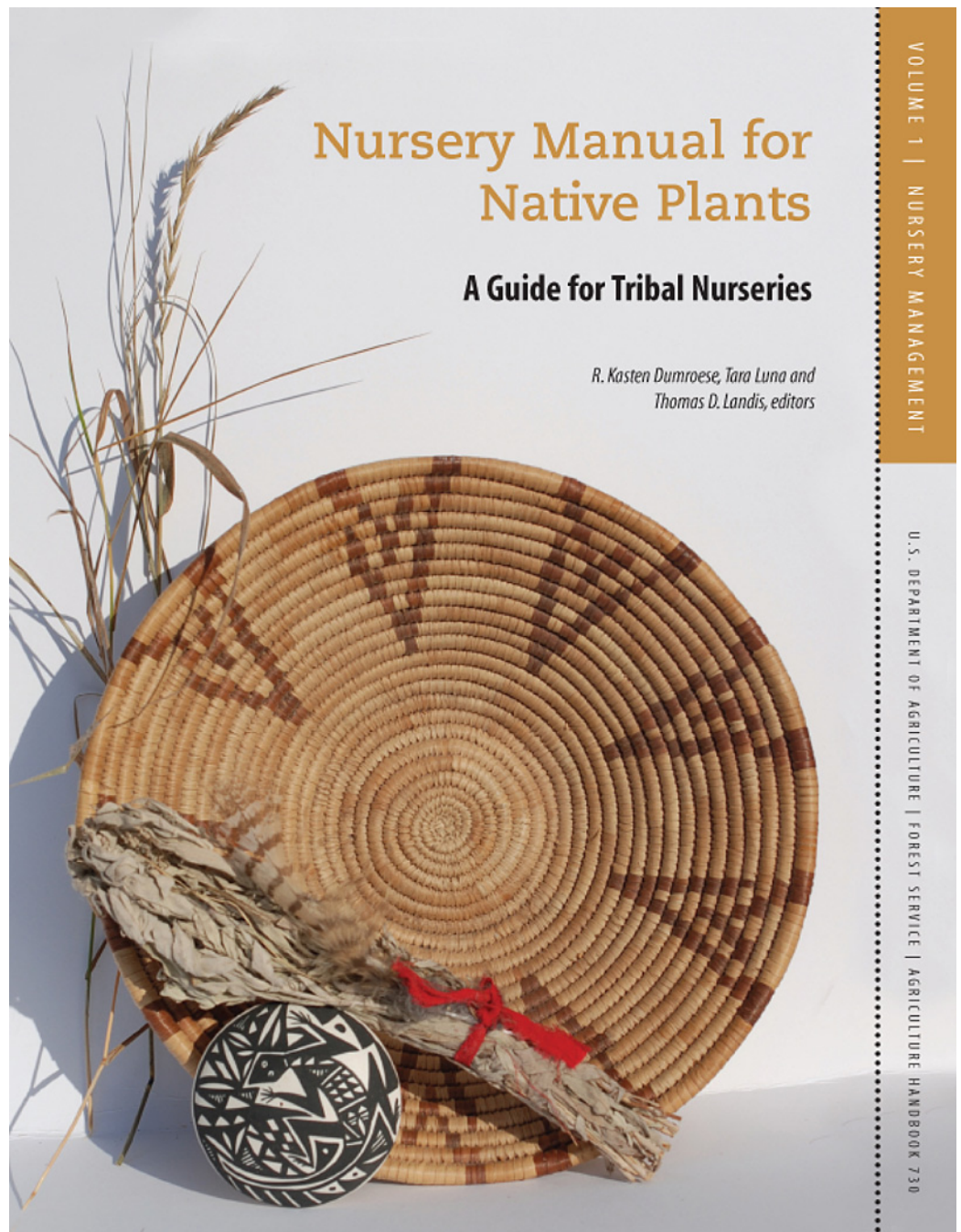




Jacobs, Douglass F.; Wilkinson, Kim M. 2009. 3: Planning crops and developing propagation protocols. In: Dumroese, R. Kasten; Luna, Tara; Landis, Thomas D., editors. Nursery manual for native plants: A guide for tribal nurseries - Volume 1: Nursery management. Agriculture Handbook 730. Washington, D.C.: U.S. Department of Agriculture, Forest Service. p. 33-53.

Planning Crops and Developing Propagation Protocols

Douglass F. Jacobs and Kim M. Wilkinson

Crop planning is an important but often neglected aspect of successful nursery management. Crop planning enables proper scheduling of the necessary time, materials, labor, and space to produce crops. Many painstaking details, such as the careful design of nursery facilities; working with clients; collecting and propagating seeds and cuttings; and making improvements in media, irrigation, fertilization, handling, and storage, go into good nursery operations. All the benefits associated with improvements in these areas, however, will not be realized without excellent crop planning. It is essential to plan crops so that high-quality plants can be delivered to clients at the agreed-on time (figure 3.1).

Native plant nurseries vary in the amount of organization necessary to plan crop production. At a minimum, the crop production process is visualized so that the crop's needs can be anticipated and met. Keeping a daily log or journal to track crop development and nursery conditions is a practice embraced by the best nursery managers. Even if written records are not used, it is valuable to consider the level of detail that can be used to plan crops. As the nursery grows in size and complexity, the value of written records correspondingly increases.

The process of crop planning usually includes the following components:

- Identify the seed dormancy of each species and apply treatments to overcome dormancy so that a reasonably uniform crop develops within a target timeframe.

Reviewing the crop schedule by R. Kasten Dumroese.



Figure 3.1—(A) The diversity of species grown in native plant nurseries calls for detailed crop planning and scheduling to ensure that (B) high-quality plants are delivered to clients when they need them. Photos by Tara Luna.

- Understand the three growth phases crops go through (establishment, rapid growth, and hardening) and the distinct requirements for each phase.
- Develop growing schedules for crop production from propagule procurement through outplanting and detail changes as the growing cycle progresses.
- List space, labor, equipment, and supplies required to support the crop during the three growth stages.
- Keep written records, including a daily log and plant development record.
- Develop and record accurate propagation protocols so that success can be replicated next time.

Exact recordkeeping is an important part of effective nursery management. A common limitation to nursery productivity is lack of species-specific and site-specific knowledge about seed treatments, germination requirements, plant development, and special crop needs. One of the greatest potential benefits of good recordkeeping is the development of specific, successful propagation protocols. A propagation protocol is a document that details all the steps necessary to propagate a plant, from the collection of seeds or cuttings all the way through shipping the plants to the field. An example propagation protocol that describes the typical development of serviceberry in a nursery in Montana is included in this chapter. Creating a propagation protocol for each species grown has these benefits:

- Invaluable resource for crop planning and scheduling.
- Beneficial for improving nursery productivity and seedling quality over time.
- Useful for teaching and sharing information about the plants to clients, the public, or nursery staff.
- A way to preserve and perpetuate propagation information.

The most important record to keep is a daily log that tracks what happens with each crop. Eventually, protocols can be developed from these logs and tailored to the unique growing conditions of a specific nursery to allow nursery managers to more readily repeat success from year to year.

This chapter will show how a propagation protocol is used to create a schedule and to plan facilities to produce a crop of a given species. Planning the schedule, management practices, and facilities for each crop

through each phase of growth will help maximize seedling growth and quality. It is recognized that crops rarely conform to the exact specifications of the protocol, but protocols and planning are essential guides to keep plants on target and to preclude potential problems at each development phase.

KEY PLANNING COMPONENTS

During crop planning, it is important to keep the process of plant production in mind. For native plant nurseries, six key crop planning components can be used to:

1. Determine available growing space.
2. Plan crop layout in the nursery based on the number of plants required.
3. Schedule propagule collection and processing.
4. Schedule propagule treatment.
5. Schedule propagule establishment.
6. Determine a growing schedule to meet a target date of delivery for “finished plants.”

1. Available Space

A nursery is only so big—the number of plants that can be produced within it will depend on the propagule type, species, and container size. A nursery will hold more small plants than large plants. It is extremely useful to know how many plants growing in a particular container can be placed on a greenhouse bench and/or within the total nursery area.

2. Crop Layout Based on Number of Plants

Determining the crop layout is “planning what crops and stock types go where” in the greenhouse or nursery. This layout is planned to effectively provide similar growing requirements (temperatures, irrigation frequency, rates of fertilization) and other cultural requirements (frequency of shoot pruning or other treatments) for all the species and stock types grown each year.

The layout is necessary so that the total number of plants required can be accommodated by the space available. Depending on numbers, species, and container sizes grown, the layout of the crop in the greenhouse will change yearly.

The crop layout is also useful for taking advantage of microenvironments within the greenhouse or nursery. Most important, species with similar growth rates and irrigation requirements need to be grouped together.

Fast-growing species with similar growing and cultural requirements can be grouped together in one area, and moderate and slower growing species can be grouped together in another area of the greenhouse. This grouping method allows for species with similar requirements and growth rates to be treated effectively and efficiently. Ideally, species requiring cooler growing temperatures can be planned for the north and east sections of the greenhouse, and species requiring warmer temperatures can be planned for the southwest section. Likewise, the flow of plants out of a greenhouse to an outdoor nursery should be taken into consideration so that plants that finish in the same timeframe can be moved out and a second crop, if scheduled, can be planned for the available empty space.

3. Propagule Collection and Processing Schedule

This schedule needs to be closely coordinated, especially when seeds or cuttings are not on hand for all species or the supply in storage is insufficient. Seeds of species that need to be treated or sown immediately after collection should be delivered to the greenhouse as soon as possible, and seeds collected and cleaned in late autumn should reach the greenhouse by a predetermined target date so they can be treated as needed for the spring crop. To develop the seed treatment schedule, collectors of seeds or cuttings need to regularly communicate with staff at the nursery regarding when delivery to the greenhouse will occur. If seeds are provided by the client, they must be received in time to undergo treatment.

4. Propagule Treatment Schedule

Having a schedule of when to treat propagules is important for planning a target sowing or cutting establishment date for the entire crop. The propagule treatment schedule is one of the most basic and necessary crop planning tasks for native plant nurseries that grow a wide variety of species. Native species vary widely in their seed dormancy, so the seed treatments need to be scheduled properly. It is important to remember that seed dormancy requirements may vary among seedlots of the same species and slightly longer or shorter seed treatment durations should be adjusted accordingly. Similarly, cuttings vary in their collection, treatment, and storage needs. Consideration of these factors allows plants of multiple seedlots and species to

establish on time so that a relatively uniform crop develops through the growing season. Making proper adjustments will mostly come with experience, although the propagation protocols in volume 2 of this agriculture handbook and the protocols available at the Native Plant Network (<http://www.nativeplantnetwork.org>) can be referenced to develop some guidelines.

The propagule treatment schedule is essentially a calendar in which the grower determines a target plant establishment date for the spring and schedules backward through the calendar months to organize all necessary treatments. For a target sowing date in March, for example, serviceberry and Woods' rose have a long stratification requirement that would need to start in November, whereas rushes and sedges generally have a 60-day stratification requirement and would go into stratification in January. If two crops per year are to be grown in the greenhouse, then a second treatment schedule must be made for a later date. If two crops are to be grown per season, the treatment schedules will overlap and the grower must pay careful attention to the scheduled treatment tasks as they appear on the calendar.

The propagule treatment schedule will need to be adjusted depending on the number of species produced, quantities of each species grown, growth rates (time required to grow the crop) of each species, and different container sizes.

For example, very fast-growing species such as western larch and many wetland species can be sown at a later date than the rest of the crop so that they do not become overgrown by the end of the season or the delivery date. Scheduling based on species may vary, however, based on cultural factors such as container size. For instance, western larch grown in larger containers will generally require longer growing periods than the same species grown in smaller containers.

5. Propagule Establishment Schedule

This schedule refers to the target seed sowing or cutting establishment date for the crop. This schedule includes, for example, instructing the sowing crew about which species need to be covered with mulch and which species require light to germinate and should be surface sown. This schedule is of critical importance because mistakes can prevent or delay emergence. The establishment schedule also includes the sowing method for each species. For most species,

direct seeding is used; however, a few species may need to be sown as germinants as they break dormancy during stratification. Establishment schedules for cuttings may include the application of rooting hormones, keeping in mind that different species may require varying types, levels, and timing of rooting hormones to effectively induce root proliferation.

The establishment schedule is also planned by considering the growth rates of species (time to grow per container size) and the dates on which plants are to be delivered or outplanted. Dates can be adjusted as needed each season. Slower growing, woody species should be sown first, and faster growing species in small containers can be sown later in the season.

6. The Growing Schedule

This schedule is the most complex component because the nursery manager must estimate the growth rate of the crop and determine when to start the crop to meet target plant characteristics. This schedule is refined as the grower gains experience and plant development records and daily logs are reviewed. Plant specifications for woody plants are usually expressed in terms of target height, root mass, and root-collar diameter (caliper), and these specifications need to be considered and may even be specified under contracts with clients. Specifications for herbaceous plants are often much different, but usually include the need for plants to have several true leaves and a plantable, healthy root mass.

The growing schedule should include the current plant inventory. The inventory needs to be updated, especially during the establishment phase of the crops, so that, if needed, extra containers can be planted to ensure that the target number of plants is produced.

The plant development records and plant inventory should include the following information:

- Species.
- Seedlot number.
- Date propagules were collected.
- Planting date.
- Project or client number.
- Target date of delivery.

CROP GROWTH PHASES

Understanding the growth phases that crops go through is essential to crop planning. A tiny germinant has very different needs and requirements than a large plant that is almost ready for outplanting. The development of most crops can be divided into three phases: establishment, rapid growth, and hardening. Plants in each of these phases have distinct requirements for light, water, nursery space, and the types of attention and labor necessary to keep them healthy. The nursery manager's objectives for the crop are also different at each phase in order to keep production on track to produce target plants. Table 3.1 summarizes some typical aspects of each of the three phases. Please note that these aspects are generalized and will not apply to all species.

Establishment

The establishment phase is one of the most critical for successful nursery operations. For plants grown from seeds, the establishment phase is defined as the phase from the sowing of the seeds through the germination, emergence, and development of the first true leaves or primary needles (figures 3.2 and 3.5). For plants grown from cuttings, the establishment phase extends from placing cuttings into containers through the development of roots and shoots. Depending on the species, the establishment phase typically lasts 6 to 12 weeks. The goal of this phase is to maximize the amount of growing space filled with healthy plants, thereby minimizing losses.

Rapid Growth

During this phase, plants, particularly their shoots, increase dramatically in size (figures 3.3 and 3.5). Often the terminal shoot begins to approach target size. Plants are still at least somewhat protected during this phase. Rapid (but not excessive) shoot growth is encouraged.

Hardening

During the hardening phase, energy is diverted from shoot growth to root growth (figures 3.4 and 3.5). Root-collar diameter and roots reach target specifications, and shoot growth is discouraged or even stopped. Plants are “hardened”—conditioned to endure the stresses of harvesting, shipping, and outplanting. They are also fortified so that they have the energy reserves

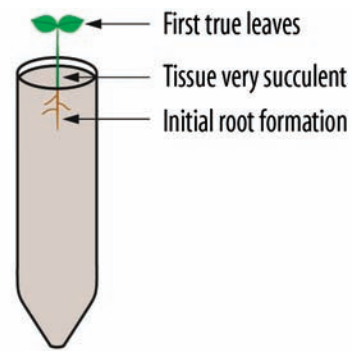


Figure 3.2—The establishment phase. Illustration by Jim Marin.

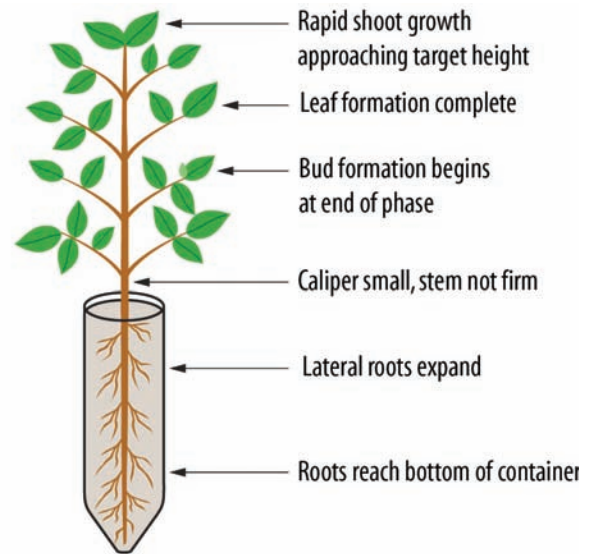


Figure 3.3—The rapid growth phase. Illustration by Jim Marin.

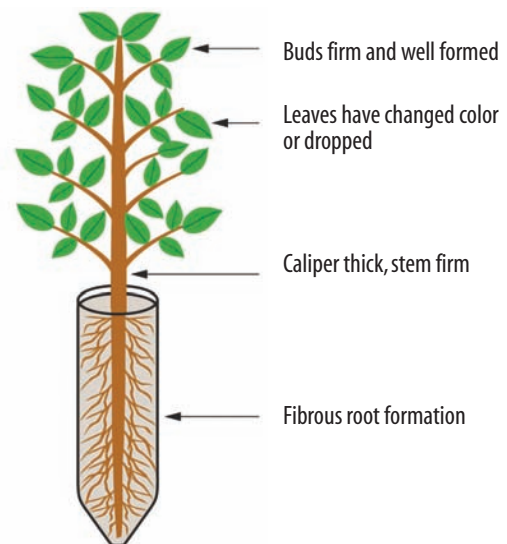


Figure 3.4—The hardening phase. Illustration by Jim Marin.

Table 3.1—The three phases of crop development for seedlings. After the three phases of crop development are understood for a species, the growing schedule can be developed to meet crop needs during each phase (after Landis and others 1998)

Phase	Establishment	Rapid Growth	Hardening
Definition	From germination through emergence and formation of true leaves	From emergence of true leaves to when seedling approaches target height; rapid increase in size, particularly in terminal shoot	Energy diverted from shoot to root growth; seedling reaches target height and root-collar diameter; lateral buds are set, seedling is conditioned to endure stress
Duration	Typically 14 to 21 days for germination; 4 to 8 weeks for early growth	Varies widely, typically about 10 to 20 weeks	Varies widely by species, from 1 to 4 months
Objectives	—Maximize uniform germination —Fill containers efficiently —Maximize survival —Minimize damping off	—Minimize stress —Encourage shoot growth —Maintain environmental factors near optimum levels —Monitor as seedling approaches target height and roots fully occupy container	—Stop shoot growth —Encourage root and stem diameter growth —Bring seedling into dormancy —Acclimate to natural environment —Condition to endure stress —Fortify for survival after outplanting
Special needs	—Protect from weather —Keep temps optimal —Irrigate to keep “moist, but not wet” —No or low fertilizer	—Protect from stress —Optimize temperatures —Irrigate regularly —Fertilize properly	—Induce moderate moisture stress —Decrease temperatures —Reduce photoperiod —Expose to ambient temperatures and humidity —Reduce fertilization rates and change mineral nutrient ratios
Labor	—Scout for pests and diseases —Monitor germination —Introduce beneficial microorganisms —Thin —Resow and/or transplant if necessary	—Scout for pests and diseases —Monitor environment —Modify density of crops to encourage good development —Adjust culture to avoid excessive shoot height	—Scout for pests and diseases —Monitor crops and environment carefully; see chapters 15 and 17 for details —Deliver crop to client in timely fashion to avoid problems with holdover stock.

to survive and grow after outplanting. Hardening is a crucial phase. It is a common mistake to rush hardening, resulting in plants poorly prepared for conditions on the outplanting site. When plants are not properly hardened, they may have the correct physical characteristics but survival after outplanting will be low because of an inadequate physiological condition. The goal of the hardening phase is to get plants conditioned for stress, prepared for outplanting, and ready to be delivered to the client in a timely fashion to avoid problems with holdover stock. See Chapter 12, *Hardening*, for more discussion on this topic.

Problems with Holdover Stock, Delayed Shipping, and Improper Scheduling

It is important to schedule and plan nursery production to make sure a crop goes through these three phases of development and is sent out from the nursery healthy and ready for outplanting. Although it is sometimes relatively easy to grow a seedling to target size, the tricky part is the hardening phase: slowing growth before plants get too large and conditioning them so they have energy reserves and can withstand stress. After plants are in this state, prompt outplanting is essential to ensure they can take full advantage of their hardened condition. If the stock is held over, problems quickly become apparent.

Many factors can disrupt the ability to follow a time schedule, but a common problem is the failure of clients to pick up plants on schedule. This problem can be avoided by good scheduling practices and communicating often with clients, especially periodic updates to advise them when seedlings will be ready. Clients tend to enjoy being kept abreast of the development of their crop, and updates about crop progress can become more frequent as the shipping date approaches. In some cases, having penalties, such as storage fees, in the contract for late pickups may also encourage clients to pick up their plants in a timely fashion. When communicating with clients, emphasize up front that prompt outplanting is in everyone's best interest, not only for the nursery and the health of the plants but also for the success of the client's project. See Chapter 16, *Nursery Management*, for more information about communicating with clients.

If the schedule to outplant after hardening is not met, however, a myriad of problems can develop. After

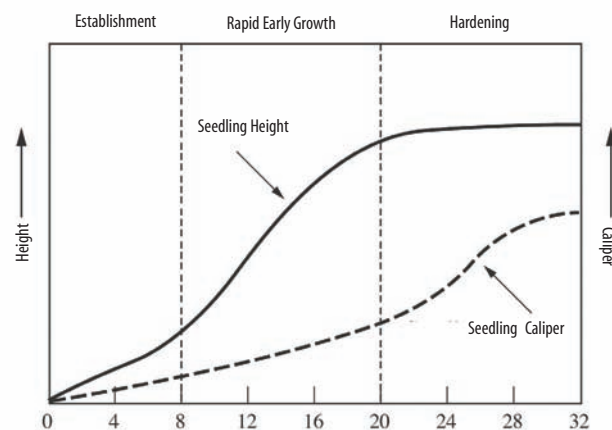


Figure 3.5—Changes in seedling morphology during the three growth phases. Growth is relatively slow during the establishment phase. Most height growth occurs during the rapid growth phase, which ends when target height specifications are met. During hardening, roots continue to grow so long as soil temperatures are favorable, resulting in an increase in seedling root-collar diameter (caliper). Modified from Wood (1994).

chilling requirements are met, a plant may begin to come out of dormancy, shoot growth begins, and it loses its resistance to stress as described in Chapter 12, *Hardening*. New vegetative growth after hardening must not happen until after the stresses of lifting and outplanting have occurred; otherwise, it may expose the plant to severe stress from which recovery may be difficult.

Problems with holdover stock include:

- loss of stress resistance.
- loss of cold hardiness.
- the swelling of buds, resulting in lost dormancy.
- the compacting or spiraling of roots, which reduces plant quality.

When plants are held too long in the nursery, the root system becomes woody and loses its ability to take up water and nutrients (figure 3.6). Structural problems may occur, too; roots may spiral (figure 3.7) and, instead of expanding outward and downward into the soil after outplanting, will strangle the plant or cause it to fall over in a high wind.

A solid understanding of the three phases of growth and how a particular species will develop over time in your nursery conditions is essential for good scheduling (figure 3.8). The process of developing specific information about each species and its timing and management is described next.

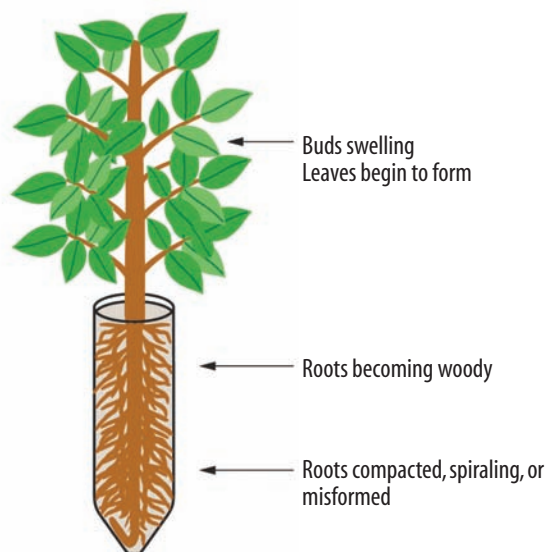


Figure 3.6—Crops that are held too long (holdover stock) may resume shoot growth and will not be properly conditioned to endure the stresses of transportation and outplanting. They may develop severe root deformities that reduce outplanting success. Illustration by Jim Marin.



Figure 3.7—The spiraling roots of 2-year-old container stock. Photo by Tara Luna.

KEEPING RECORDS MAKES PLANNING EASIER

Site-specific and species-specific information about managing a crop of plants throughout its three phases of growth can be developed by keeping some simple records. The following three kinds of records are crucial for success:

A **daily log** is a journal that notes nursery conditions and management practices on a daily basis.

Plant development records are kept for each crop of plants and record the development and management of that particular crop. These records are usually updated at least on a weekly basis as the crop develops.

Propagation protocols are created for each species and are designed to be a comprehensive guide describing how to grow that species in your nursery from propagule collection through outplanting. Propagation protocols are usually revised on a seasonal or annual basis.

These three records interrelate and support each other (figure 3.9). For species not grown before, the first step is doing some preliminary research to develop a draft propagation protocol, which is simply a best guess on how to propagate and manage that species. Literature, interviews with colleagues at other nurseries, a search for protocols written by other nurseries posted on the Native Plant Network (<http://www.nativeplantnetwork.org>), and personal experiences will inform this draft protocol. After the plants start growing, direct personal experiences (as recorded in the daily log and plant development records) will be used to refine and update the protocol regularly to improve production. The daily log is used to fill in any gaps or to track issues that come up in the plant development records, and the plant development records enable you to compare actual crop development with the protocol.

Daily Log

It is easy to get caught up in the day-to-day details of running a nursery and lose sight of how important it is to write down what is happening. Nothing compares, however, with that sinking feeling that occurs after shipping out a successful crop of beautiful plants and suddenly realizing that nobody knows how to replicate that successful crop. How long did it take to produce the crop? What materials were purchased? How was the crop fertilized, watered, and managed during each growth phase? Keeping records of plant development and general nursery activities is an essential part of good nursery management.

A daily log or journal is simply a record of what was done and what happened in the nursery each day (figure 3.10). Appendix 3.C includes a blank daily log form and a daily log example that a small nursery with a staff of just one or two people might use. Make it a habit to at least jot down something each day, even if only a minute is spent on it. Large nurseries may keep more complicated daily records and may have separate logs for irrigation, fertilization, and the like. Tailor the daily log to suit the nursery. The important thing is just to do it. What is recorded in the daily log about management practices, environmental conditions, and general crop performance will become a priceless resource for many years to come.

Some growers choose to record a large amount of detail in their general daily log and then go back to the



Figure 3.8—Serviceberry at different growth phases: (A) germination and establishment, (B) establishment phase 4 weeks after germination, (C) early rapid growth phase in early summer, (D) late rapid growth phase in midsummer, and (E) hardening phase in outdoor nursery in late autumn. Photos by Tara Luna.

daily log at slower times of the year to summarize specific information about each crop into a plant development record. Many growers, however, find it easier to keep a separate plant development record for each crop, as described in the following paragraphs.

Plant Development Record

Keeping a simple plant development record (or register) for each crop is a great way to build a foundation for accurate, site- and species-specific protocols. A plant

development record notes what is happening with a crop of plants from crop initiation through delivery. The plant development record helps you track and remember exactly what you did to produce a crop. These notes about management practices and timing for each phase of growth are invaluable records. At a minimum, you can simply put a couple of fresh sheets of paper in a notebook or three-ring binder and jot down notes on a regular basis (at least weekly) as the crop progresses. One way to make it easier to keep track of this valuable informa-

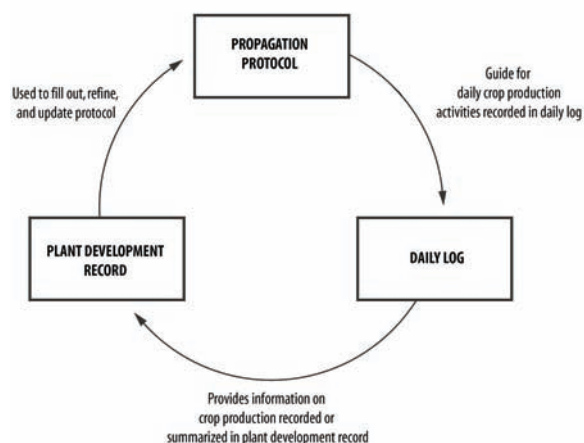


Figure 3.9—The three basic records and how they relate. Use a protocol (originally drafted from research, literature, and experience) to plan and schedule daily activities. Daily activities are recorded in the daily log. Keeping a log helps with collection of specific information about the development of each crop. This information is recorded in the plant development record for each crop. The protocol is then refined and expanded based on this new information, which will improve scheduling and production practices the next time the crop is grown.



Figure 3.10—Jot down a few notes every day about what was done and what happened with the crop. These records become invaluable resources when adjusting protocols and fine-tuning crop schedules. Photo by Tara Luna.

tion is to create a form such as the one provided in Appendix 3.D. You can photocopy this form, put it in a three-ring binder or clipboard, and fill it out as each crop progresses. You can also refine the form to match the conditions and the crops grown in your nursery. Use a blank form for each crop grown, even if it is just a small trial of a few plants or even if the species has been grown before. It is sometimes easier to remember to record these notes if the form with a pen attached to it is conveniently accessible a short distance from the crop. Filling out the form can also be done on a computer. Every time you work with the crop or make an observation about it, jot a note in the record. These records quickly become great storehouses of information for developing and updating protocols.

Propagation Protocols

A propagation protocol describes all the steps necessary to grow a species in a specific nursery and is meant to be a guide to producing and scheduling a crop of that species. A protocol is ideally comprehensive, systematic, and detailed like a cookbook recipe, although new nurseries may begin with relatively skeletal protocols that become more detailed as experience accumulates. A protocol contains significantly more detail than the plant development record, usually providing information on propagule collection and some background information about ecology and distribution. The more information a protocol contains, the easier it will be to plan and schedule crops.

The example protocol in Appendix 3.B shows the type of information usually included. Many completed protocols for native plants are available online at the Native Plant Network (<http://www.nativeplantnetwork.org>), an excellent place to start research as you develop protocols for species in your nursery. Remember, however, that a protocol used by another nursery cannot be explicitly applied to any other nursery, but it can be used as a guide to help develop a site-specific protocol.

A protocol typically describes the following aspects and characteristics:

- Species name and ecotype.
- Time to grow.
- Plant target specifications (for example, height, root system, root-collar diameter).
- Propagule sources and collection.

- Propagule characteristics and processing.
- Preplanting propagule treatments.
- Growing area preparation.
- Management for, and length of, establishment phase.
- Management for, and length of, rapid growth phase.
- Management for, and length of, hardening phase.
- Harvesting, storing, and shipping practices.
- Duration of storage.
- Outplanting notes.

Gathering Information

Ideally, each nursery has a protocol that provides detailed information for each species it grows. Nurseries that work with native or culturally important plants may need to develop protocols from scratch. Even when a familiar and widely propagated species is grown, the exact schedule and performance of that species will vary greatly depending on the unique conditions of the nursery and on other variables such as seed sources and weather patterns. In other words, no one else's propagation "cookbook" can be applied exactly to your nursery; you need to develop your own unique "recipe" to produce the best plants. It can be very helpful to create and share protocols with clients so that they understand the nuances and timing factors necessary to provide them with high-quality plants.

The development of the protocol is informed by both firsthand experiences and outside sources of information. Keeping a good daily log and plant development record during crop production can be used as the foundation for building protocols. Outside information sources should also be explored, including published literature, personal observations of the plants in the field, and information from other growers (Landis and others 1999).

PUBLISHED LITERATURE

A systematic search can reveal information on how to propagate the species. Trade journals, native plant societies, and botanical gardens may be able to help. An excellent source of propagation protocols, continually updated by growers and free of charge, is online at the Native Plant Network (<http://www.nativeplantnetwork.org>). If specific information on the species to be grown is not currently available, try to find a similar species grown in similar climatic zones to see if any information may be applicable.

PERSONAL OBSERVATIONS OF THE PLANT IN THE FIELD

Clues can be gained from studying how the plant grows in nature. This information may be gained firsthand from observation and also from published literature and/or community members who are familiar with the plant. Although collectors of plant materials for cultural uses may have never grown the species, they are likely to be knowledgeable about the species life cycles.

INFORMATION FROM OTHER PROFESSIONALS

Private nurseries may be disinclined to share their propagation methods, but government nurseries or botanical gardens are often excellent sources of information about growing the same or similar species. Again, information generously shared by other growers in the Native Plant Network is invaluable.

Writing the First Draft

Based on information gathered and firsthand experiences, a draft protocol is created. This first draft is the "best informed guess" of what will be required and how the species may perform in your nursery. This new protocol will serve as a guide as you work through the first crop cycle. The plants themselves will prove the protocol right or wrong as they grow. The daily log and plant development record will enable a comparison between projected development and actual growth. Information will be expanded and improved as the nursery gains more site-specific experience. Revise the protocol regularly according to how the species and seedlot actually behaved under local conditions. Ultimately, the nursery will have a very accurate guide for how to grow that species.

Testing and Adjusting Protocols

Refine and update the protocol with site-specific information from your nursery after the production of each crop. Do not be discouraged if a protocol drafted from background research or another nursery's experience does not produce the same results; the goal is to adjust the protocol to reflect local conditions. Remember that year-to-year variations in weather or unforeseen operational changes may prevent crops from growing exactly as projected. Allow some room for flexibility and make adjustments based on observed factors. Sometimes the protocol will need to be adjusted to more accurately reflect how crops actually develop;

sometimes management practices are adjusted to enable crop development to match the specifications of the protocol. The protocol is continuously updated and revised as plants and experiences grow, making it more accurate year by year.

Protocols are not only a guide for producing current crops but also a foundation for the improvement of crop production. Along with plant development records, they provide baseline information that enables nursery managers to determine if intended improvements (such as the introduction of new beneficial microorganisms or a different type of fertilizer) actually have a positive impact on plant health and growth compared with what was normally done. New nurseries especially benefit from updating protocols, as refinements are made and dramatic improvements are seen in crop production efficiency and effectiveness from season to season. Propagation protocols serve as an essential guide for planning and scheduling each future crop.

Planning Crop Production: Time and Space

After a draft protocol has been developed for a species, it is time to plan the crop. Two main factors in crop planning are time and space. For illustration purposes, the example protocol in Appendix 3.B will be used to create a schedule and facilities plan to produce a crop of serviceberry. Crop planning covers all phases of crop production, from the procurement of plant materials through outplanting. It also provides an overview of the schedule for bringing crops through the three growth phases (establishment, rapid growth, and hardening) and of storage. It is also essential to plan for the space, materials, and other facilities that the crops will require: containers and benches in the nursery, equipment, supplies, and materials and labor needed at each phase to produce a successful crop.

Crop Growing Schedules

Crop growing schedules show all phases of nursery production from the procurement of plant materials through outplanting. It is important to account for the time needed to obtain seeds or cuttings and the time required for seed processing, testing, and treatments, if necessary. This schedule creates a visual illustration of each step in the protocol and the time necessary to complete each step. When the timing for nursery crops is understood, appropriate dates for sowing seeds or

sticking cuttings can be calculated by counting *backward* from the desired date of outplanting. The accurate calculation of field-ready dates is essential for successful client relations. For example, serviceberry for spring outplanting requires 15 months to grow, including time for stratification prior to sowing. So, if plants are needed for outplanting in March, as shown on the schedule, the stratification must begin in January of the previous year (figure 3.11). (Note that if seeds of this species are not in storage, they will need to be collected in late summer.) The total time required for the production of each crop (a variety is shown in figure 3.11) will vary widely by species, season, and nursery environment. Genetics and the variability of seedlots will also cause variations in crop scheduling.

A detailed schedule of the three different phases of crop development should be created based on the protocol. This schedule will show how to accommodate the changing needs of the crops as they develop. Table 3.2 provides examples of the necessary steps in each phase (transplanting emergents, thinning, moving from the propagation structure to the rapid growth structure, changing fertilizer and watering regimes, and so forth) and the time required to complete each step. This schedule should be posted in the nursery so that staff can track the crop's development and understand what cultural practices are required. The schedule should clearly answer questions such as, "What water and fertilizer requirements does the crop have today? What aspects of crop development should receive special attention?" If appropriate, the schedule can also be shown to clients so they fully understand the time required to produce their crop.

For more complicated crop production, schedules can be created easily with computer spreadsheets and divided into two separate calendars: (1) a year-long, monthly calendar with week-by-week general steps and (2) a second, more detailed schedule displaying day-by-day activities for the production of each crop.

Because the three distinct phases of crop development usually involve moving crops from one nursery structure to another, discussion about matching growth phases with nursery structures is continued in the next section.

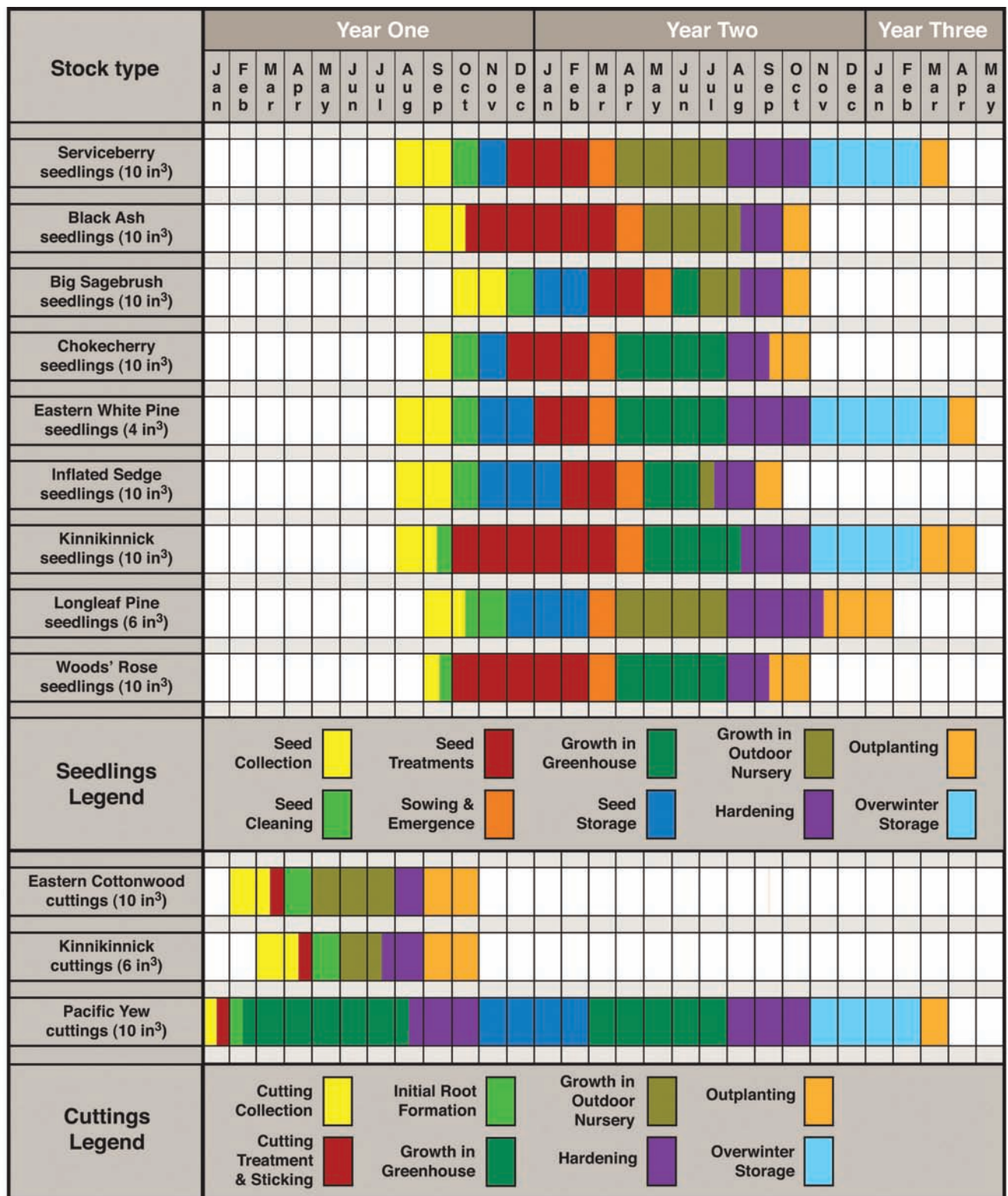


Figure 3.11—The production of a crop of serviceberry plants, the example used throughout this chapter, would require about 19 months according to this hypothetical crop growing schedule. Other stock types and species may require more or less time depending on many factors, including the availability of seeds or cuttings, seed dormancy issues, propagation environments, and the scheduled time of outplanting. Illustration by Jim Marin.

Table 3.2—An example of a crop development schedule

Activity	Seed Treatment	Establishment Phase	Rapid Growth Phase	Hardening Phase	Storage
Length of phase	17 weeks	4 weeks	16 weeks	4 weeks	16 to 20 weeks
Date	Jan 12 – May 4	May 5 – Jun 1	Jun 2 – Sep 21	Sep 22 – Oct 12	Oct 13 – Mar 1
Temperature	37 °F (3 °C)	60 to 77 °F (16 to 25 °C)	60 to 77 °F (16 to 25 °C) (ambient outdoors)	40 to 68 °F (5 to 20 °C) (ambient outdoors)	28 to 50 °F (-2 to 10 °C)
Propagation environment	Refrigerator	Germinant house	Main outdoor growth area	Main outdoor growth area	Outdoor compound under insulation
Fertilization	None	1 g Osmocote® per 172 ml Cone-tainer®	13N:13P ₂ O ₅ :13K ₂ O at 100 ppm weekly	10N:20P ₂ O ₅ :20K ₂ O at 100 ppm every other week	N/A
Irrigation	N/A (keep moist)	Daily handwatering to saturation	Daily auto overhead to saturation	Gradual reduction	N/A
Target size at end of phase	N/A	N/A	10 cm (4 in) height, 4 mm caliper	10 cm (4 in) height, 7 mm caliper	Same as hardening phase
Activity	Cold storage stratification	Thinning at 2 weeks	Weed and pest management	Protect from early frost	Monitoring temperature and insulation

N/A = not applicable

Space and Facilities Planning

The space requirements in each facility for each crop during the different stages of propagation must be planned. These plans also include labor, equipment, and supplies needed to support crop development through each growth phase.

As plants develop through the growing cycle, their needs will change. Except for nurseries with elaborate climate control systems, crops are often moved from one structure to another as they progress through the three development phases (see Chapter 4, *Propagation Environments*, for additional information on this topic). Using the serviceberry example, crops are protected in a special germination area during the establishment phase and then moved to an outdoor growth area for rapid growth and hardening (table 3.3). Likewise, the amount of space the crop will require varies by growth phase: germinants may take up very little room if they are concentrated in trays, but plants take up much more space after they have been transplanted into larger containers or spaced more widely as they grow bigger. Although the example in table 3.3 does not go into such detail, the facilities schedule should calculate how much space each crop will use, how many



Figure 3.12—Plants are often moved from one area of the nursery to another as they go through the three growth phases. Good planning and scheduling ensures that the space will be available to meet the needs of the crops, as shown here at the Santa Ana Pueblo Nursery in New Mexico. Photo by Tara Luna.

hours of labor will be needed, and the quantities of materials (for example, growing media) required during crop production.

It is especially important to consider the material and labor needs at each phase of crop production. The facilities schedule should answer questions such as, “What materials will be needed in the next weeks or months? What action do we need to take: for example, pot media, clean containers, and clear off benches to

make room for the new crop? What labor and attention does the crop require this week and this month? Will this effort involve fertilizing, watering, and/or moving the crop to a new structure?”

Planning how each facility will be used is indispensable in determining how resources within a nursery can be best distributed to maximize production and minimize conflicts associated with overlapping needs (figure 3.12). The facilities schedule (table 3.3) may be combined with or posted side by side with the crop schedule, and the staff should have easy reference to it.

Nursery Inventory

The recordkeeping and scheduling efforts described previously make it very simple to keep track of nursery inventory. An inventory should include a listing of all plants in the nursery by bench or structure number, the current developmental stage of the crop, and details of delivery (site, name of owner, anticipated delivery date).

Keeping the inventory and growing schedules posted in a central place in the nursery helps all the staff under-

stand the current needs of the existing crops; equipment and supplies needed, as dictated by schedules; and the necessary practices to keep the crop on schedule.

SUMMARY

Crop planning is an important process to help schedule time and facilities and commit to delivery dates for plants. A daily log or journal is a key aspect of nursery management, because it records a way to track what happens with each crop and provides a history of crop development. This information helps create accurate, site- and species-specific protocols for growing plants. For new species, the first protocol may be drafted from outside sources of information and experience and then revised based on actual crop performance in your nursery. The protocol is used to make a good schedule for the crops and bring them through the three growth phases so that the plants are healthy and conditioned for out-planting. The daily log and the records of plant development should be used to continuously refine the protocol on a seasonal or annual basis, resulting in increasingly

Table 3.3—An example of a facilities schedule

Activity	Seed Treatment	Establishment Phase	Rapid Growth Phase	Hardening Phase	Storage
Length	17 weeks	4 weeks	16 weeks	4 weeks	20 weeks
Date	Jan 12 – May 4	May 5 – Jun 1	Jun 2 – Sep 21	Sep 22 – Oct 12	Oct 13 – Mar 1
Labor	—Clean seeds in hydrogen peroxide: soak (20 minutes) followed by 48-hour rinse; —put in mesh bags or into flats; —keep moist; —rinse seeds weekly	—Make growing media; —fill containers; —plant seeds; —hand-water daily; —monitor germination; —thin or consolidate as necessary; —monitor greenhouse temperature	—Move to outdoor growth area after danger of frost is past; —use liquid fertilizer weekly; —monitor overhead automatic irrigation; —monitor outdoor temperature; —monitor growth; —manage weeds/pests	—Monitor growth; —monitor and gradually reduce irrigation and fertilization	—Move to storage area; —cover with insulating foam —monitor temperatures and insulation —pack and distribute when planting time comes
Facility/ space needed	Refrigerator	Benches in germinant house	Benches in main outdoor growth area	Benches in main outdoor growth area	Space in outdoor storage area
Materials needed	—Seeds; —3% hydrogen peroxide; —water; —stratification media (<i>Sphagnum</i> peat moss); —net bags; —flats or trays	—Stratified seeds; —containers and trays; —potting media (peat, perlite, vermiculite, Osmocote®)	13N:13P ₂ O ₅ :13K ₂ O liquid fertilizer	10N:20P ₂ O ₅ :20K ₂ O liquid fertilizer	Insulating foam; boxes or containers for shipping out seedlings

accurate information to support successful crop production. The amount of detail incorporated into schedules and plans for nursery crops is a personal decision and is influenced by how complicated the production system is. It may be unrealistic for smaller nurseries that grow small quantities of many different species to consistently maintain all the records described here. If so, start with a daily log and expand to more written records as time and resources permit.

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APPENDIX 3.A. PLANTS MENTIONED IN THIS CHAPTER

big sagebrush, *Artemisia tridentata*
black ash, *Fraxinus nigra*
chokecherry, *Prunus virginiana*
eastern cottonwood, *Populus deltoides*
eastern white pine, *Pinus strobus*
huckleberry, *Vaccinium* species
inflated sedge, *Carex utriculata*
kinnikinnick, *Arctostaphylos uva-ursi*
longleaf pine, *Pinus palustris*
Pacific yew, *Taxus brevifolia*
red alder, *Alnus rubra*
rushes, *Juncus* species
sedges, *Carex* species
serviceberry, *Amelanchier alnifolia*
western larch, *Larix occidentalis*
Woods' rose, *Rosa woodsii*

APPENDIX 3.B. EXAMPLE PROTOCOL *AMELANCHIER ALNIFOLIA* (SERVICEBERRY)

Native Plant Nursery
Glacier National Park
West Glacier, Montana 59936

Common Name: Serviceberry

Family Scientific Name: Rosaceae

Family Common Name: Rose family

Scientific Name: *Amelanchier alnifolia* Nutt.

Ecotype: Forest margin, Saint Mary, 1616 meter (5300 foot) elevation,
Glacier National Park, Glacier Co., MT

Propagation Goal: Plants

Propagation Method: Propagated from seeds

Product Type: Container (plug), 172 ml Cone-tainer® (10 in³ Ray Leach Super Cell)

Time to Grow: 11 months (for fall planting); 15 months (if overwintered and
planted in spring)

Target Specifications:

Height: 10 cm (4 in)

Caliper: 7 mm

Root system: Firm plug in 172 ml Cone-tainer®

Propagule Collection: Seeds are hand collected in late summer when fruit
turns dark purple. Seeds are tan at maturity. Fruits are collected in plastic bags
and kept under refrigeration prior to cleaning.

Propagule Processing: Seeds are cleaned by maceration using a Dyb-vig seed
cleaner followed by washing and screening. Seed longevity is 5 to 7 years at 3 to
5 °C (37 to 41 °F) in sealed containers. Seed dormancy is classified as physiological
dormancy.

Seeds/kg: 180,400 (82,000/lb)

Purity: 100%

Germination: 15% to 100%

Pre-Planting Treatments: 3:1 water:hydrogen peroxide (3 parts water to 1
part 3% hydrogen peroxide), soak for 20 minutes followed by a 48 hour water
rinse. Seeds are placed into a 120 day cold moist stratification after pretreatment.
Seeds are placed in fine mesh bags and buried in stratification media in ventilated
containers under refrigeration (3 °C [37 °F]). It is very important to wash stratified
seeds weekly; remove net bags from artificial stratification and rinse well to
remove mucilaginous material. Lower germination percentages were noted
with seedlots that did not receive the hydrogen peroxide and water rinse prior
to stratification. This pretreatment of seed appears to significantly improve
germination percentages.

Growing Area: Greenhouse and outdoor nursery growing facility.

Sowing Method: Direct Seeding. Seeds are lightly covered with medium.

Growing medium: 6:1:1 milled sphagnum peat, perlite, and vermiculite with
Osmocote controlled release fertilizer (13N:13P₂O₅:13K₂O; 8 to 9 month release
rate at 21°C [70 °F]) at the rate of 1 gram of fertilizer per 172 ml Cone-tainer®.

Environment/Water: Greenhouse temperatures are maintained at 21 to 25°C
(70 to 77 °F) during the day and 16 to 18 °C (60 to 65 °F) at night. Seedlings are
hand watered and remain in greenhouse until mid May, after establishment.

Seedlings are then moved to outdoor nursery for the remainder of the growing
season. In the outdoor area, seedlings are irrigated with Rainbird automatic
irrigation system in early morning to saturation (until water drips out the
bottom). Average growing season of nursery is from late April after snowmelt
until October 15th.

Establishment Phase: Germination is uniform and is usually complete in 3 weeks.
True leaves appear 2 weeks after germination. Seedlings are thinned at this stage.

Length of Establishment Phase: 4 weeks

Rapid Growth Phase: Seedlings grow at a rapid rate after establishment. Plants
are fertilized with soluble 13N:13P₂O₅:13K₂O at 50 to 75 ppm during the growing
season. Plants average 10 cm (4 in) in height and 4 mm caliper in 4 months.

Length of Rapid Growth Phase: 16 weeks

Hardening Phase: Plants are fertilized with soluble 10N:20P₂O₅:20K₂O at 100 ppm
during August and September. Irrigation is gradually reduced in September
and October. Plants are given one final irrigation prior to winterization.

Length of Hardening Phase: 4 weeks

Harvesting, Storage, and Shipping: Total time to harvest: 11 months for fall
planting, 15 months if overwintered and outplanted in spring.

Harvest Date: Fall or spring

Storage Conditions: Overwinter in outdoor nursery under insulating foam cover
and snow.

Length of Storage: 4 to 5 months.

Outplanting performance on typical sites: Outplanting site: Saint Mary, Glacier
National Park, MT. Outplanting date: spring or fall. Outplanting survival at 4 years:
86%.

Other cultivation comments: Seedlings in 3-liter (1-gallon) containers average
65 cm (25 in) in height with 10 mm caliper 16 months following germination.

General comments: Distribution: *A. alnifolia* occurs from southern Alaska to Califor-
nia, east across Canada to western Ontario, south through the Rocky Mountains to New
Mexico, and east to the Dakotas and Nebraska, in open forests, canyons, and hillsides
from near sea level to the subalpine zone. *A. alnifolia* is a long-lived seral species that
is widely used in restoration projects in many habitats. Deer, moose, and elk browse the
foliage and twigs, and berries are an important food source to birds and mammals.
There are 3 botanical varieties; *var. pumila*, *var. humptulipensis*, and *var. alnifolia*.

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APPENDIX 3.C. DAILY LOG FORM

Date:

Environmental conditions in growing areas (light, temperature, humidity):

Sunrise/Sunset times:

Moon phase:

Other weather notes (cloud cover, and so on):

What water did seedlings receive? (irrigation type and frequency, or precipitation):

Today's activities (note how many person-hours per activity) (fertilization, pest management, transplanting, packing and shipping, making potting media, moving crops from one structure to another, treating or sowing seeds, and so on):

Growth phase status (make notes when a crop moves from one phase to another):

Purchases (what supplies or equipment were purchased and their cost):

Orders (what plant materials were delivered and payments made):

General crop/nursery observations:

Questions or concerns:

DAILY LOG SAMPLE

Date: April 2, 2008

Environmental conditions in growing areas (light, temperature, humidity):

Min/Max Temp: Outdoor area: 60°F min; 75°F max, indoor area: 68°F min; 80°F max.

No artificial lighting used, just sunlight.

Sunrise/Sunset times: Sunrise: 6:45 am Sunset: 7:00 pm

Moon phase: Full moon tonight!

Other weather notes (cloud cover, and so on): Partly cloudy, no rain today.

What water did seedlings receive? (irrigation type and frequency, or precipitation):

Hand-watered germinant area with fine-headed sprayer in a.m.. First thing in the morning, automatic overhead watering for 1 hour on all seedlings in main greenhouse and benches one through six in outdoor area.

Today's activities (note how many person-hours per activity) (fertilization, pest management, transplanting, packing and shipping, making potting media, moving crops from one structure to another, treating or sowing seeds, and so on):

Mixed potting media and filled trays for the new order for 500 serviceberry seedlings, 3 hours total.

Hand-watered the germinant area, 1 hour. Fixed the leak (noticed yesterday) in the main water line, 1 hour.

Answered e-mail correspondence, 1 hour. Fertilized the 8-week-old serviceberry and huckleberry seedlings in greenhouse area with 200 ppm Peter's 20-20-20, 1 hour. Moved new alder seedlings from establishment area to main greenhouse, 1 hour.

Growth phase status (make notes when a crop moves from one phase to another):

The red alder seedlings sown earlier this month have entered the rapid growth phase—today I moved them from the germinant area to the main greenhouse. They are about 3 inches tall now.

Purchases (what supplies or equipment were purchased and their cost):

Bought a new coupling for fixing the irrigation line, plus an extra one to have on hand in case there is another leak: \$10.87.

Bought potting media materials for serviceberry order, \$28.45.

Orders (what plant materials were delivered and payments made):

No plants going out until September. Order confirmed for 500 serviceberry.

General crop/nursery observations:

Things look good in general. The huckleberry were starting to look a little yellow, which is why I switched from the other fertilizer to the 20-20-20 today. I'm pleased with how the alder look...it seems the inoculation I did 3 weeks ago might be kicking in. I don't see any nodules yet, but they look green despite no nitrogen fertilizer, and roots have that ammonia-like smell I was reading about.

Questions or concerns:

I'd like to check the media pH for the huckleberry...they like it acidic and maybe I need to adjust more. Everything seems fine so far but I'd like to stay vigilant so I can nip any problems in the bud. There seem to be lots of slugs out...because of all the rain last week? I'd like to explore some organic slug control options...maybe I'll call around and see if anyone I know has had success with that copper barrier stuff, and what the cost might be.

APPENDIX 3.D. PLANT DEVELOPMENT RECORD FORM

Species name: _____

Seedlot/Seed source: _____

Date of seed collection: _____

Establishment

Type and length of propagule treatment (scarified, stratified, and so on):

Date of propagule establishment: _____

Potting media and tray or container type used:

Germination notes (date begins and ends, % germination, and so on):

Date transplanted (if not direct sown):

Container type and potting media for transplanting:

Microorganisms used?

Irrigation type and frequency: daily, every other day, and so on

Fertilization (type, rate, and frequency, if any):

Environmental conditions for crop (light, temperature, humidity):

Horticultural treatments (cultivation practices, and so on):

Date establishment phase completed:

Notes (resowing or thinning activities, problems, or challenges):

Rapid Growth

Time after sowing to enter rapid growth phase:

Plant size at start of phase (height):

Container type and potting media:

Irrigation type and frequency: daily, every other day, and so on

Fertilization type, rate, and frequency:

Environmental conditions for crop (light, temperature, humidity):

Horticultural treatments (spacing, cultivation practices, and so on):

Date rapid growth phase completed:

Notes (development, vigor and health, challenges, or problems):

Hardening:

Plant size at start of phase (height and root-collar diameter):

Irrigation type and frequency: daily, every other day, and so on

Fertilization type, rate, and frequency:

Environmental conditions for crop (light, temperature, humidity):

Horticultural treatments (spacing, cultivation practices, and so on):

Plant size at end of phase (height and root-collar diameter):

Date hardening phase completed:

Date plants delivered:

Notes (vigor and health, challenges, or problems):

Other notes

Notes on performance of crop after outplanting
