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9 Natural Regeneration: The Seed-Tree Method

Introduction

In the **seed-tree method**, a harvest is carried out to remove most of the trees in a mature stand, leaving a small number of residual trees (called **seed trees**) to produce the seed for regenerating a succeeding stand. In general, the seed trees are harvested soon after the new seedlings have been established. The stand will have a two-aged structure for a short period, but it will return to an even-aged structure after the seed trees have been harvested. Variations in the method include the seed tree numbers, timing of cutting, and harvest patterns; these are described in detail in this chapter.

Reserve trees can be incorporated into the seed-tree method in order to maintain a long-term two- to three-aged forest structure. Reserves can include intact forest patches and other structures. This method is called **seed tree with reserves**, and is described in detail in Chapter 11. Systems with reserves are defined as **irregular** because of their multi-age-class distribution and their more heterogeneous canopy structure.

The main goal of the seed-tree method is to regenerate tree species that have fairly large seed, often partially wind- or animal-dispersed seed, and are intolerant or mid-tolerant of full sun. The method usually requires bare mineral soil with little or no vegetative competition. Favorable tree species for the seed-tree method include most pines and spruces, Douglas-fir, tulip-poplar, ash, and mahogany, which all have a wing-like structure attached to the seed. However, tree species that produce nuts and rely upon gravity and rodents for their dispersal (e.g., oaks, chestnuts, hickories) can sometimes be successfully regenerated through seed-tree methods as well. Irrespective of their mode of dispersal, most trees that require the seed-tree method are *masting*, meaning that they fruit prolifically, but at very erratic intervals of time (e.g., once every 10 years). Using the functional guild categorization (see Chapter 5), these species would be considered long-lived pioneers of stem exclusion or late-successional canopy dominants.

Species regenerated with the seed-tree method require the same kind of open conditions and lethal site treatments as those regenerated with a true clearcut method of regeneration. The difference is that the focus species in the seed-tree method have seed that is poorly dispersed, and thus needs a nearby parent tree source within the regenerating stand to secure satisfactory stocking. The method of dispersal itself is inclusive of species that regenerate within clearcuts (i.e., dispersed by wind, water, small bird, bat). Species that regenerate prolifically in clearcuts are not dispersal-limited, and will seed into seed-tree treated stands automatically (see Chapter 8). Examples of species that regenerate prolifically without seed-trees include the very shade-intolerant species such as birches, aspens, willows, sycamore, and red alder, which produce quite small seeds that are dispersed in large numbers over long distances. In addition, there are species that germinate from buried seed banks (pin cherry), and species from serotinous cones (lodgepole pine, jack pine).

Seed-tree regenerated stands usually comprise mixtures: pioneers suited to clearcuts as well as the heavy-seeded species that are the focus of the method itself. The seed-tree method does not favor tree species that require partial shade and moisture for germination or that rely upon vegetative propagation. However, the method is often used in combination with clearcuts for species that are compatible with both regeneration methods, especially for species that have some degree of dispersal limitation and site preference for best germination (e.g., Douglas-fir, southern pines). Regional examples where forest types are preadapted to lethal disturbances are therefore in the same types as where true clearcuts are practiced. However, seed-tree methods emulate sub-lethal disturbances (e.g., where several trees survive the crown fire), rather than a lethal disturbance. Seed-tree methods thus reflect areas of a disturbance such as a wildfire, where individual trees survive because of a sheltered aspect or close distance to water that served to protect individual trees. Similar to clearcuts, the seed-tree method is appropriate for many sites in the Intermountain West, the pinelands of the southern US, and the interior fire-prone boreal of Canada (Table 9.1).

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Table 9.1 Examples of the natural disturbance regimes of forest types and species that can be regenerated by the seed-tree method in North America.

Region and species/ forest type	Regeneration, disturbance regime, and return interval
Interior boreal	
White spruce/aspen	White spruce has a transcontinental range but its core distribution is across the Canadian interior. In this region, aspen is an early successional associate. The return interval for stand-replacing fires is 60–200 years. Aspen immediately responds by root suckering with other pioneers (willow and birch), but spruce seedlings will develop for a longer period of time from seed-tree sources that survive or escape the fire. Spruce overtops the aspen after 50–80 years
Pacific Northwest	
Douglas-fir	The range of Douglas-fir almost extends across all of western North America from the middle of British Columbia to the border with Mexico. Its range is from sea-level in the North to elevations that increase and become more fragmented progressing south in the Rockies. Seed mast years vary with 1 good year in every 7. Given its shade-intolerant and relatively fire-tolerant tendencies, seed-tree cutting is a more secure way of establishing regeneration than clearcutting on more extreme sites within the coastal mountains
Intermountain	
Western larch	Western larch is a deciduous conifer of the central Rocky Mountains that is the shade-tolerant long-lived pioneer, compared to its associates: Engelmann spruce, subalpine fir, western hemlock, western white pine, and interior Douglas-fir. Good seed crops occur about every alternate year, but don't disperse further from the parent tree more than about 150 ft (50 m). The tree is the most fire resistant and windfirm of its associates making it ideal for the seed-tree method of regeneration
Ponderosa pine	Ponderosa pine is widely distributed across the central region of western North America, but not on the coast. It has many growth forms and many common names. The tree dominates stands and forests at the intermediate-to-lower elevations of the mountains, but can be found as a scattered emergent in the more mesic mixed stratified forests of the Sierra Mountains, and interior cedar–hemlock with Douglas-fir at higher elevations. Surface fires were common and patchy prior to colonization, burning at intervals of 5–20 years. Such fires kept these stands open and park-like, devoid of more mesic-loving species. At higher elevations, fires were more of mixed severity, burning more intensely with patches that were stand replacing
Gulf Coast/southeast coastal plain	
Longleaf pine	The distribution of longleaf pine rings the coastal plain from North Carolina to Louisiana, but mostly occupies former marine sediments that are excessively well drained and coarse to poorly drained clays. Its associated species are scrub oaks, and the slash, sand, and loblolly pines. It dominates stands where frequent groundstory burns reduce the understory oak and hardwood component, and promote an open pineland. Return intervals vary from 3–10 years
Middle west	
Bur oak woodlands	Bur oak occurs and dominates the eastern and central forests of the Midwest bordering the tall-grass prairie. It is associated with calcareous soils of ancient inland seas and fine glacial loess of uplands, but can also be an associate of river-bottom forest. Its resistance to fire and its drought tolerance make this tree a dominant of fire-prone woodlands that were repeatedly burned by Native Americans for game, and homesteaders for clearing land. Bur oak masts every 2–3 years, with seedlings that sprout vigorously after surface fires that can occur every 2–5 years
Northern hardwood	
Black cherry/black birch	The black cherry and black birch species are shade-intolerant long-lived pioneers that require mineral soil and a lethal disturbance to dominate a stand without more the shade-tolerant trees that they are usually associated with (sugar maple, red oak, beech, eastern hemlock). No natural disturbance regimes in northern hardwood forests would promote these species alone, unless there was a severe enough wind disturbance (i.e., tornado, hurricane) to be almost sub-lethal. Both species are thin barked and fire intolerant like most northern hardwood species

Source: Mark S. Ashton.

Additionally, seed-tree methods can emulate localized sub-lethal disturbances in a broad range of forest types, such as flooding along rivers, small landslides, and patchy fires, often associated with people and agricultural clearance in wetter temperate and tropical forest types. In fact, many tree species were purposely left in agricultural clearances within the forest (also called swiddens), with the intention of regenerating the old agricultural patches back to forest, richer in timber, latex, and fruit trees that could be harvested later. As in true clearcuts, creation of the necessary conditions for establishment requires heavy-handed site preparation measures.

The Protocol

The seed-tree regeneration method generally involves only three cuts, in the following order.

1) **Preparatory cut**: preparatory cutting may be needed to improve the strength and vigor of trees destined to be left as seed trees. This is needed only for dense stands that contain tall, thin trees with small crowns and poor seed production, which generally result from a lack of thinning in previous years.
2) **Seeding cut**: this cut removes most of the trees in the stand, and opens up a large portion of vacant growing space in a single harvest operation to allow regeneration to develop. This initial regeneration cut is often called the **seed-tree cut**. Site preparation is often associated with the seeding cut; it creates the appropriate conditions on the forest floor for seed germination and early seedling development.
3) **Removal cut**: this cut removes the seed trees and releases the established regeneration to full sun, or nearly full sun. This cut is usually done soon after seedlings are established, but in some cases, the seed trees are retained for a longer period after the seedlings have been established in order to obtain greater timber value from the growth of these seed trees.

The Preparatory Cut

A seeding cut in dense stand conditions would likely lead to windthrow. To solve this problem, a preparatory cut can be carried out several years before the seeding cut, and would generally take the form of a thinning. It could be a heavy low thinning to release growing space throughout the stand, or it could be equivalent to a crop-tree thinning where the seed trees would be designated to remain, and only the trees competing with the seed trees would be cut. The several additional years of growth after the preparatory cut will increase the wind firmness and the seed production of the remaining trees in the stand, and thus the stand will be ready for the seeding cut.

The Seeding Cut

Selection of Seed Trees

It is crucial that the selected seed trees be able to withstand the greater wind speeds that occur after the seeding cut has opened up the stand (Logan, Edwards, and Shiver, 2002). The best trees for wind firmness are those in the dominant crown class that have wide crowns and large live crown ratios; these trees will also tend to have strong tapering stems (Asselin, Fortin, and Bergeron, 2001). If the stand had been thinned in the past or had been a naturally low-density stand, the dominant trees generally can withstand the sudden change in stand density. There are some situations, though, where soils are very shallow and it would probably not be possible to use the seed-tree method at all (Emmingham *et al.*, 2005).

It is also necessary to select trees that can produce abundant fertile seed. Only trees in the upper canopy have enough vigor to produce large seed crops, but a few good seed trees sometimes produce as much seed per acre as the full stand did before the seeding cut. The choice of potential seed trees can sometimes be made by observing numbers of cones or seed fall from trees in previous years. These trees could be marked to be retained as seed trees. It would be ideal if foresters could also choose trees with genetic traits for good stem form, rapid growth rate, and defenses against insect and disease damage. However, because the genotypes of each tree are not known, the selection depends on the observation of phenotypes of the trees in the stand. This amounts to selecting some of the most valuable trees in the stand to serve as seed trees. This is called positive genetic selection, although there is no quantitative measure of potential genetic improvement that can be made just from observation. The very best seed trees are those that have the desired phenotypic traits of tree growth and form, biological defenses, and good seed production.

Number and Distribution of Seed Trees

The number of seed trees to be retained depends on several factors: the size of the trees, the amount of seed produced per tree, the percentage of seeds that are sound (viable), and the number of seeds needed to produce an established seedling, given the particular seedbed conditions. The balance of these factors generally leads to seed tree numbers of about 3–20 trees/acre (7–50 trees/ha) depending upon tree species. A standard pattern for locating seed trees is to have them uniformly spaced as single individuals throughout the stand in order to produce a roughly even amount of seed fall throughout the stand.

Tree seeds can be blown a great distance by the wind, often for many hundreds of feet. The greatest distance occurs on dry days with strong winds, but most seed disperse from moderate winds and local turbulence. The goal in seed-tree management is to have a seed density that is great enough to meet the need for adequate regeneration. Much of the seed from a tree falls under the tree crown or nearby, which then follows an exponential decline in seed density over greater distance from the tree. For example, about 10% of Engelmann spruce seeds can disperse up to 600 ft (180 m), while 50% of the seed fall was within 100 ft (30 m) of the parent trees (Alexander, 1987). Loblolly pine has a dispersal measure of 73% of the seeds within 100 ft (30 m) of parent trees. Longleaf pine has a heavier seed, and 88% of the seeds fall within 100 ft (30 m) of the parent stem (Boyer 1958). Similarly, trees that produce nuts that are partially dispersed by gravity and by caching territorial rodents or birds, need to be spaced to accommodate dispersal limitations (Gómez, Garcıa, and Zamora, 2003; Forget *et al.*, 2005; Gómez, Puerta-Piñero, and Schupp, 2008). Thus, the importance of high seed density often leads to limiting the distance between seed trees to about 100 ft (30 m).

The number and distribution of seed trees will first influence the pollination of female flowers (angiosperms have flowers and gymnosperms have strobili, but the term "flower" will be used here for simplicity). A few species, such as white ash, cottonwood, and some maples are dioecious; both female trees and male trees of these species must be retained in the stand in order for seeds to be produced. Most tree species are monoecious, having both female flowers and male flowers on each tree. If self-fertilization occurs, it usually results in aborted seed ovules or seeds with poor vigor. However, the male and female flowers of the same tree rarely mature at the same time. In addition, female flowers tend to develop in the upper part of the tree crown, above the male flowers in the lower crown, and the wind is generally not turbulent enough to cause much pollen to rise straight upward. These evolutionary adaptations reduce the amount of self-fertilization. However, if there are only a very small number of trees left in a stand, self-pollination will be more likely to occur (Greene *et al.*, 1999). Thus, a greater number of seed trees spaced more closely together will give an increased chance of cross-pollination, so larger numbers of seed trees will result in both larger numbers of seeds and higher percentages of sound seed in the crop (Box 9.1). To promote regeneration of dioecious tree species (e.g., ash, cottonwood, ebony tree) it is important to ensure that both sexes are represented in the stand, and if there is a desire to increase stocking of the species, then a disproportionate number of female trees need to be left strategically spaced across the stand (Guariguata and Pinard, 1998).

Annual Variation in Seed Crops

Some tree species with small seeds produce large numbers of seed regularly every year. However, many other species with larger seeds have irregular cycles with dramatically different amounts of seed crops each year. These cycles range from 2 years to 10 or more years. Species with these distinct cycles are called **mast species** and the years with the large crops are called **mast crops** (or **bumper crops**). In years without mast crops, most of the tree seeds are consumed by rodents, birds, insects, and other organisms. During a mast year, the high production of tree seeds overwhelms the ability of the seed predators to consume all the seeds. It is during these years that seeds can survive and germinate in large numbers.

Many tree species have variable seed crops, especially the pines, Douglas-fir, and spruce (Cain and Shelton, 2001; Lamontagne and Boutin, 2007), the nut-producing flowering trees like dipterocarps of southeast Asia (Curran and Leighton, 2000), and the oak and chestnut of North America and Eurasia (Ostfield and

Box 9.1 Seed-tree regeneration for shortleaf and loblolly pine on the Piedmont.

Introduction

Shortleaf and loblolly pines grow naturally on the poorer soils of the Piedmont of North Carolina and Virginia with hardwoods such as red maple, sweetgum, and a variety of oaks. It was originally a minor component of the forest prior to land colonization and clearance for agriculture. However, with the abandonment of cotton cultivation (primarily to its decimation by the boll weevil), much of the land came back as pure stands of shortleaf and loblolly pine at the last century and was cutover in the 1940s. Most of the land is now third- or fourth-growth, having been harvested for timber several times over. Most is owned by private landowners interested in a variety of values, particularly outdoor recreation, wildlife habitat, and income from timber, making the seed-tree system very compatible with their interests. Industrial land owners usually rely on more intensive site preparations and plant pure loblolly.

Regeneration

The seed-tree method for shortleaf and loblolly pine in the Piedmont of North and South Carolina relies upon a dependable but periodic seed mast and soil seedbed conditions that expose mineral soil that is moist for germination with high sunlight for seedling establishment (see Fig. 1 and 2). Site preparation requires surface mineral soil

Box 9.1 (Continued)

Box 9.1 Figure 1 Seed-tree cut for loblolly pine (*Pinus taeda*) with broadcast herbicide application prior to scarification. *Source:* B. Lockhart, US Forest Service, Bugwood.org. Reproduced with permission from B. Lockhart.

Box 9.1 Figure 2 Seed-tree cut for shortleaf pine (*Pinus echinata*) with slash that has been chopped and crushed, prior to prescribed burning. *Source:* R. Wittwer, Oklahoma State University, Bugwood.org. Reproduced with permission from Bugwood. Org.

by prescribed burning or mechanical scarification. This process increases contact between the seed and the mineral soil for best germination. Burning and scarification can be done pre- or post-harvest but need to be tied to masting events, as favorable seedbeds quickly become occupied by herbaceous vegetation. Also, seed trees need to be protected from either mechanical or fire damage. The seeding cut needs to be timed to a good seed year (about every 3 years) and should leave 6–12 evenly distributed, well-formed trees per acre (10–30 trees/ha). The number of seed trees left depends on tree size and site conditions. The seed trees should be at least 10 in (25.4 cm) DBH, but preferably seed trees to be left when it comes time to regenerate, can increase the crown vigor and seed production within stands that are closed canopied and that exhibit strong crown competition. If hardwoods are present in the understory, additional site preparation treatments may be necessary using a foliar herbicide to forbs and grasses, a spray application to the basal stems for shrubs, and stem injection to the bole for larger hardwood trees. A delay in seedfall means that the seedbed will likely have to be re-scarified or re-burned (if sufficient fuels exist). A fully stocked stand results in about 1000 well-distributed seedlings per acre (2500 seedlings/ha).

Keesing, 2000; Frey *et al.*, 2007). For example, the seed crop sizes for loblolly pine and shortleaf pine in Arkansas have been studied for 20 years (Cain and Shelton 2001). In that period, there were mast crops of more than 800,000 seeds/acre (2,000,000 seeds/ha) for 6 of the years; good crops of 40,000–800,000 seeds/acre (100,000–1,680,000 seeds/ha) for 9 of the years, and poor crops of less than 40,000 seeds/acre (100,000 seeds/ha) for 5 of the years. In this case, there were never two poor crops in a row, so there would not be a problem to conduct a seed-tree cut with a good crop or better in the 2-year period of seedling establishment. However, other species have longer periods without good seed crops, such as longleaf pine which often have five or more poor seed-crop years in a row.

Site Preparation

Many forest types develop thick forest-floor material and well-established understory vegetation as the stand ages. Most tree species with wind-dispersed seeds need a mineral-soil seedbed for germination, and moderate to full sun for seedling height growth. Similarly, masting species need nuts to be effectively buried, and germinants of masting species do not compete well with rival vegetation. Site preparation may be necessary to create the appropriate forest floor and understory conditions. Prescribed fire, herbicides, and mechanical treatments to scarify or uproot the forest floor can be used to promote the establishment and growth of seedlings. The most efficient approach is to have the site preparation treatments carried out as part of the initial seed-tree harvest. However, if there is a poor seed crop in the year of the seeding cut, then it is possible to delay the site preparation until a good seed year occurs. Site preparation methods are similar to those described for clearcuts in Chapter 8 or in more detail in Chapter 7.

The Removal Cut

The standard practice regarding removal cutting is to have all seed trees cut soon after the regeneration has been safely established. The timing depends on the species growth rates, sites, and climate (Bragg, 2010). The height growth of the regeneration is an indication of how well the seedlings have become established. Foresters will often wait until the seedlings reach 1–2 ft (30–60 cm) in height before making the removal cut. For fast-growing species, such as loblolly and shortleaf pines, that means that the seed trees generally can be cut 3–5 years after the seeding cut. However, with other species it could be more than 5 years, especially in more northern climates with the slower establishment of red pine or spruce. Another aspect of timing with the removal cut is the need to limit damage to the new regeneration. The stems of the young seedlings are flexible enough that they can recover after moderate damage from harvest equipment; however, if regeneration reaches larger sapling sizes, damage from equipment will likely break the rigid stems rather than just bending them, resulting in failure to fully recover.

Dealing with finances, a very different problem, often arises with removal cutting. In some cases, the harvesting costs of cutting the seed trees can often be greater than the value of the timber in the seed trees. Although when the best and largest trees are left, they are usually the most valuable. However, in a situation where the standing seed trees are a financial loss and are not removed, the seedlings will be gradually shaded by expansion of the seed-tree crowns. There are several general options to deal with this problem. One is to plan at the outset to keep a greater number of seed trees than is needed for seed dispersal, so that there are enough trees to have a merchantable operation in the removal cut. This will likely cause some reduction in growth of the regeneration. Another option is to retain the standard number of seed trees, but keep them as reserves for a longer period than is needed for ensuring that the regeneration is well established. These seed trees have no crown competition so they will be growing rapidly; a diameter goal for the seed trees can be set to determine the time of the removal cutting. Again, there will be some reduction in growth of the regeneration. A third option might be to girdle the trees and turn them into snags once their function of providing seed is accomplished. This has the added value of creating old growth and interior forest structures valuable for certain species of wildlife that would not frequent early-successional stands. See Box 9.2.

Box 9.2 Seed-tree/shelterwood regeneration for longleaf pine.

Longleaf pine can be regarded as a shade-intolerant pine, very drought tolerant, and tolerant of groundstory fires. Compared to loblolly and slash pine, seed dispersal is more limited and considerably more sporadic. Longleaf can be very long lived, and prior to colonization it formed extensive stands of old growth across the lower gulf, comprising very open stands on sites that were droughty and relatively nutrient poor. Fire was the natural disturbance regime that prevented the other more fire-sensitive loblolly and slash pines from establishing, and prevented the colonization of hardwoods. The woody understory hardwoods needed to be controlled. Without natural fires the alternative is prescribed burning which needs to be conducted at fairly frequent intervals to maintain the openness for the herbs and grasses with enough space for establishment of the fire-tolerant longleaf pine (Fig. 1).

Box 9.2 (Continued)

Longleaf pine is fire tolerant because of its "grass stage", in which the young seedling takes a period of time to sequester and develop a large tap root and the needles serve to insulate the stem. The even-aged natural regeneration method that is most suited for longleaf can be considered a hybrid seed-tree/shelterwood method, given its autecology. Site preparation involves controlling understory vegetation but not eliminating it, and longleaf itself was relatively more shade tolerant than its close relatives. However, its shade intolerance and its tolerance of drought and fire, and its inability to compete with most other woody vegetation, makes it suited to a seed-tree method (see Chapter 10 for a description of the shelterwood method of regeneration).

(a)

(b)

(c)

Box 9.2 Figure 1 Longleaf pine–wiregrass ecosystems. (a) A prescribed fire completed in the fall, prior to seed fall beneath a seed tree cut. The burn was designed to kill hardwood competition back to the ground and to provide growing space for longleaf pine regeneration. *Source:* D. J. Moorhead, University of Georgia, Bugwood.org. Reproduced with permission from D. J. Moorhead. (b) The grass stage of longleaf pine depicted with the foliage of three understory oak hardwood competitors (left to right: turkey oak, willow oak and blackjack oak). *Source:* Mark S. Ashton. (c) The removal of the seed trees and the release from grass stage of a young stand of longleaf pine. *Source:* US Forest Service.

Variations in Spatial Patterns of Stand Structure

In most seed-tree cutting, the seed trees are isolated from one another and are rather uniformly distributed in the stand. However, other patterns consist of retaining the seed trees in groups, strips, or rows. These alternative arrangements may serve to accommodate other considerations. Concentrating the seed trees in restricted areas (such as linear rows) makes them easier to protect during the initial cutting and also easier to harvest after they have served their purpose. In these strip methods, after the seed trees are cut, site preparation and direct seeding or planting can be used to fill in the open strip areas, if necessary. Arrangement in rows could be appropriate if the method is applied across slopes. The lines of trees could serve both to disseminate seed and protect against surface erosion (Figs. 9.1 and 9.2).

Sometimes seed trees are arranged in small groups instead of isolated individual trees. Using a few carefully selected groups of trees can reduce the edge effect of crown shade on the ground where maximum sunlight is desired and provides greater stability to wind and other elements (Lieffers *et al.*, 1996). These groups are also likely to produce less seed. A preparatory cut several years before the seed-tree cutting would generally be a better alternative unless there are other considerations such as maintaining larger groups of structures for wildlife habitat.

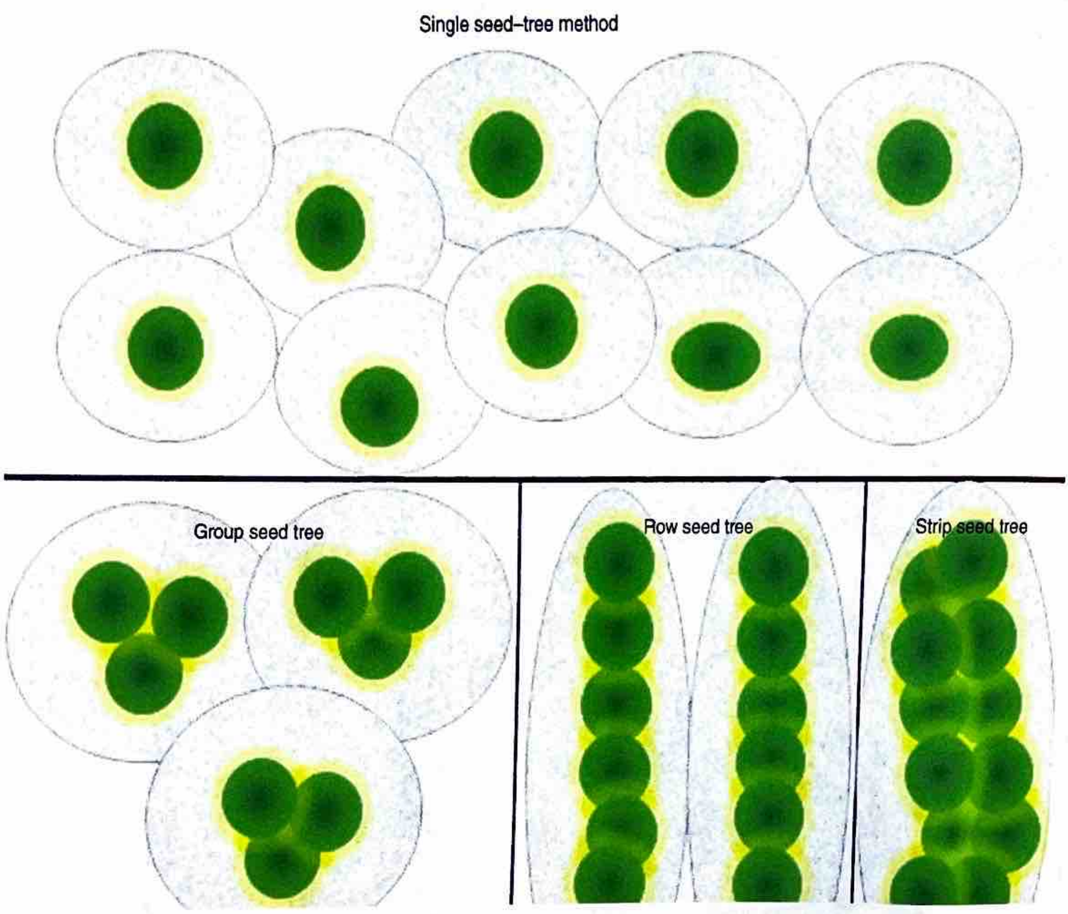


Figure 9.1 A birds-eye view of seed-tree arrangements using single trees, groups, and rows and strips. The usual method is to select trees singly and uniformly across the stand to maximize seed rain and dispersal as depicted in the single seed-tree method, whereby the crowns of the trees are shown in green and their seed-shadows are shown in grey. Trees need to be wind-firm and to be prolific seed producers. Groups are used to reduce the edge effect and maximize solar radiation on the ground surface per unit area of crown or basal area. Groups provide structural support for unstable trees and shelter and habitat for wildlife. Strips and rows aligned along with the contours can be used on steep slopes to mitigate any potential for erosion and to facilitate logistics of harvesting. *Source:* Mark S. Ashton.

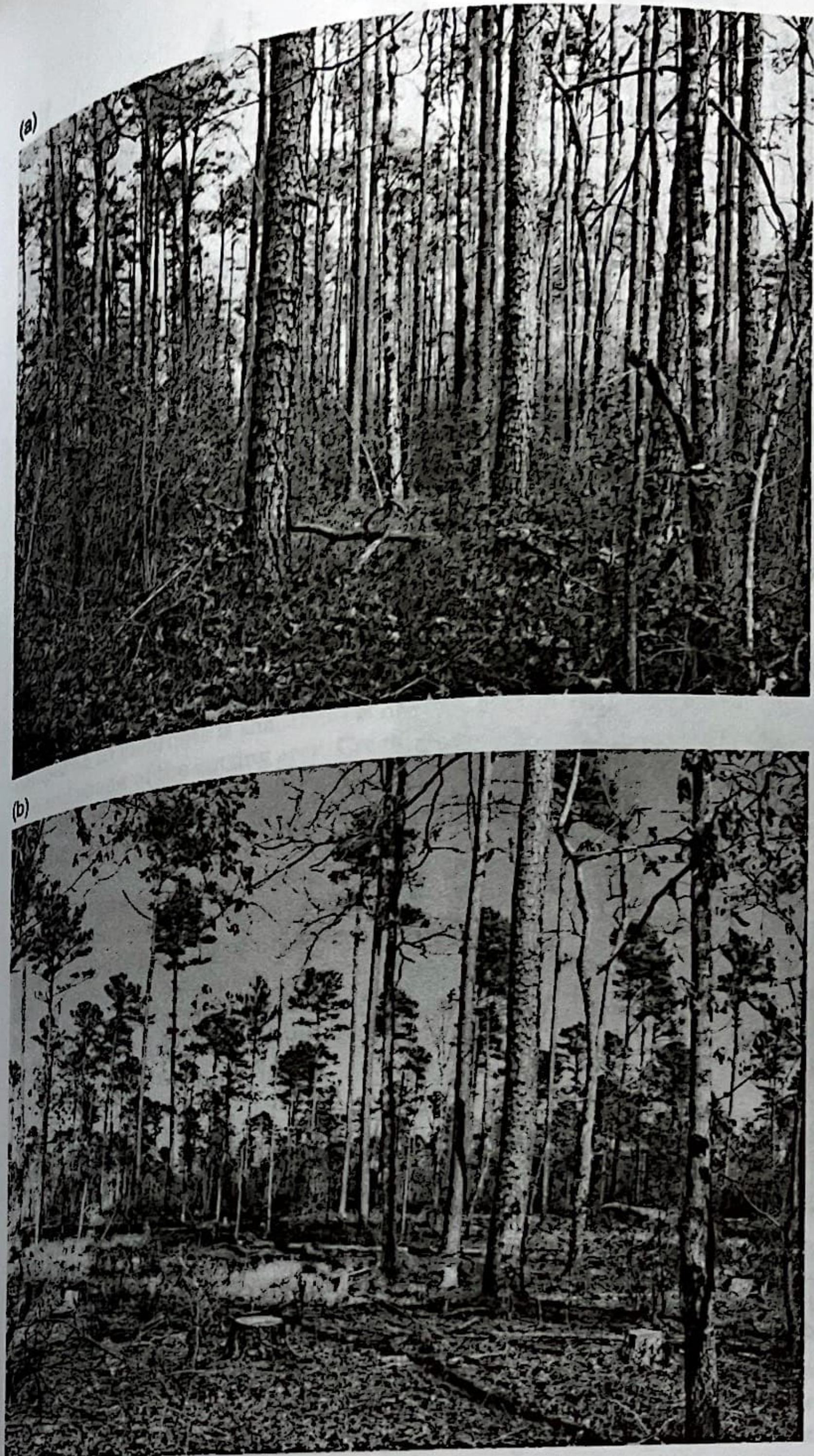


Figure 9.2 (a, b) The before and after seed-tree treatment for a 95-year-old stand of loblolly pine in the Piedmont, North Carolina. The single-tree method left about 10 trees/acre (25 trees/ha). The larger hardwoods were killed with herbicides and a prescribed burn killed the smaller hardwoods, disposed of the slash, and prepared the seedbed. *Source:* Yale School of Forestry and Environmental Studies.

Application of Seed-Tree Methods

The seed-tree method was used as early as 1450 for regenerating conifer stands in Germany, using single trees and groups of trees for seed sources (Heske, 1938). This method has continued on for centuries in many countries as a low-cost means for establishing new stands, mostly of conifer species (Fig. 9.3a). In the

(a)

(b)

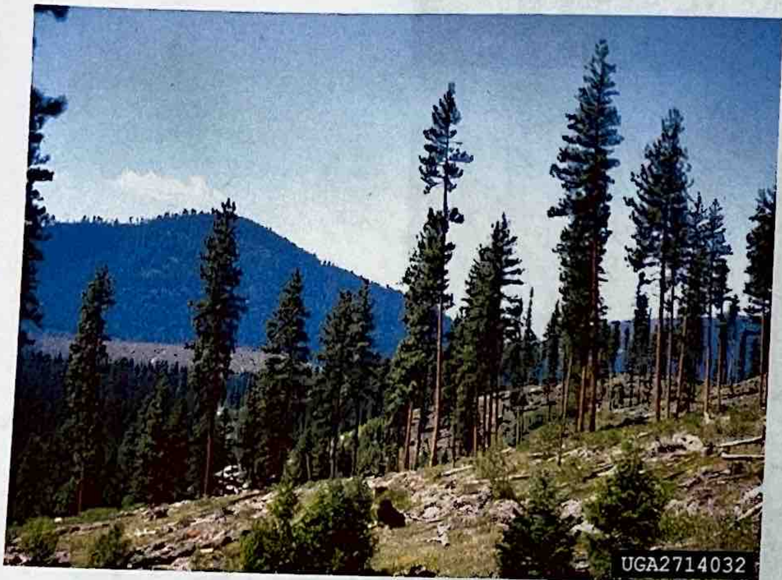


Figure 9.3 (a) Scots pine (*Pinus sylvestris*) seed-tree cut in Finland with 25–30 trees/acre (60–75 trees/ha); mean DBH 14 in (35 cm) with slash that has been chipped and taken off site and the soil surface has been scarified. *Source:* D. B. Kittredge. Reproduced with permission from D. B. Kittredge. (b) Ponderosa pine (*Pinus ponderosa*) seed-tree cut with 8–10 trees/acre (20–25 trees/ha) in western Montana. *Source:* D. Maguire, Bugwood.org. Reproduced with permission from D. Maguire.

past, the seed-tree method was often used as the initial silvicultural step in regenerating cutover and exploited forests that had not yet been managed. However, about 50 years ago, in order to obtain better control of species and stocking, forest industry began investing greater amounts of money into clearcutting with planting or direct seeding on their timberlands, and placed less reliance on natural regeneration methods such as seed-tree methods. Part of this was the desire to take advantage of the genetically improved plant or seed stock that had become available. Conversely, many private non-industrial landowners have not been willing to invest substantial money at the outset for the costs of seedlings, planting, and site preparation, with the risk that is always present, so seed-tree systems are still very much in operation.

Figure 9.4 Black birch (*Betula lenta*) and black cherry (*Prunus serotina*) seed trees (4–5 per acre) in northern hardwood forest of the Allegheny Plateau, Pennsylvania. *Source:* B. Lockhart, US Forest Service, Bugwood.org. Reproduced with permission from B. Lockhart.

One substantial advantage of the seed-tree method compared to clearcuts is that there is no limit in terms of size and shape of the cutting area. Creating a fully stocked stand from seed dispersal is dependent on adjacent stands to produce the seed fall. Given the locations, sizes, and shapes of clearcuts, there will be many situations where a clearcut might not be successful (Fig. 9.4). The seed-tree method can work regardless of the size or shape of the land because the source of the regeneration is retained on the site. Some examples of seed-tree methods are described here for the southern pine, Intermountain Regions of the US, the oak of the northeast, and the mahoganies of the wet tropics.

Seed-Tree Methods in Southern Pines

Natural pine stands are common across the southeastern US, from Virginia to Florida in the east, to Arkansas and eastern Texas in the west. The most widespread pine species is loblolly pine, which is often mixed with shortleaf pine, especially in the west of the region. These stands usually have a component of hardwood species mixed in, which include red maple, sweetgum, blackgum, and many oak species. There are greater amounts of hardwoods in the eastern range than the west because of the greater precipitation in the east.

Most of the old-growth timber in this region had been cut centuries ago, and the land had been shifted over to agriculture. From 1650–1850, the crops consisted mostly of indigo, tobacco, rice, and cotton. Cotton became the major crop for many decades, but it collapsed in the 1920s because of the invasion of the boll weevil, an insect species that invades and destroys the cotton crop. The abandonment of the agricultural fields provided open land that was a natural seedbed for the pioneer loblolly pine species (Billings, 1938; Bormann, 1953). There was enough natural pine seed in many areas to produce fast-growing loblolly seedlings.

As these old-field stands developed into dense, mostly unmanaged stands, a number of forest researchers began to conduct studies on regeneration of the next forest (Bormann, 1953). The importance of the forest-floor litter soon became clear; pine seeds needed to fall onto the mineral substrate in order to germinate (Grano, 1949, 1954). A standard natural regeneration method for loblolly and short-leaf pine seed-tree methods is to have 4–16 trees/acre (10–40 trees/ha) with trees of about 12–16 in (30–40 cm) diameter at breast height (DBH). The number of trees that are retained varies, depending upon species (generally more for shortleaf), as well as site and seedbed conditions. The goal is to have 1000 trees/acre (2500 trees/ha) of regeneration. Success depends upon proper site treatments in the fall that is timed to masting events at the same time. Seedbed conditions need to be either freshly scarified or burned to expose the mineral soil and to reduce or eradicate any vegetative competition (for more details see Box 9.1 and Box 9.2).

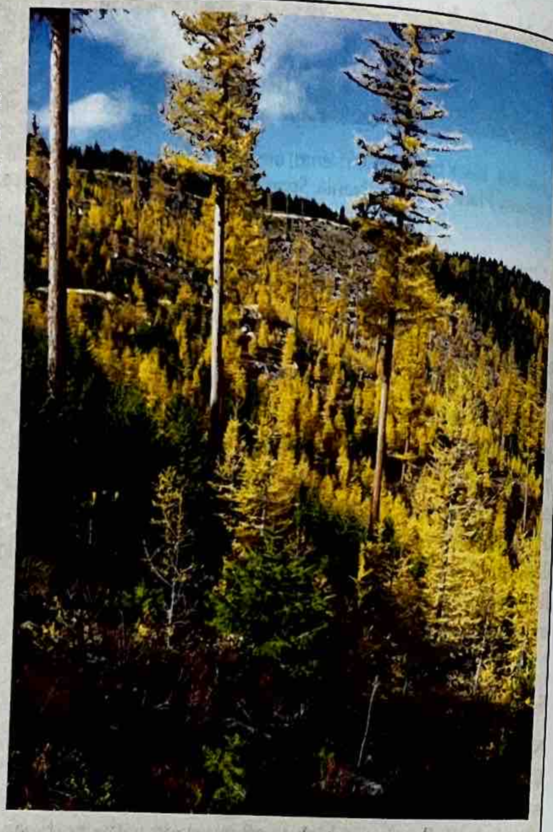
Seed-Tree Methods in the Intermountain Region

Prior to European settlement, the Intermountain Region of the western US had always had strong regional top-down climate drivers such as droughts that influenced the severity and frequency of insect outbreaks and fires (Heyerdahl, Brubaker, and Agee, 2001). Superimposed on this temporal variation is bottom-up, watershed-scale influences of topography, elevation, aspect, and soil type, that influence the severity and frequency of disturbance. Prior to timber exploitation, land clearance, and grazing, all of these drivers played important roles in shaping the forest composition and structure of the Intermountain forests. Dry forests at lower elevations and hotter southern and eastern aspects were dominated by ponderosa pine to the north (Washington, Oregon, British Columbia, Idaho, Wyoming, Colorado, Montana) or the pinyon–juniper complex to the south (Nevada, Utah, New Mexico, Arizona). Before land colonization and logging, ponderosa pine forests burned twice as frequently and earlier in the growing season in their southern ranges, as compared to their northern range, suggesting longer summers and drier climates in the south. Higher elevation and northern aspects were colder and moister, dominated by subalpine fir and Engelmann spruce, but evidence suggests the same phenomena: more frequent fires in their southern ranges, and less frequent but more

Box 9.3 Using the seed-tree method in western larch.

Introduction

Western larch (*Larix occidentalis*) in the Intermountain Region of western Montana, northern Idaho, southwest Alberta, and southeast British Columbia often grows in mixture with lodgepole pine (*Pinus contorta*) west of the continental divide. Fire chronologies suggest that this forest mixture had fires of mixed severity that ranged from underburns to patches where it was lethal and stand replacing, and which burned at intervals of 25–75 years (Barrett, Arno, and Key, 1991). In addition, there is evidence that in other areas there were much more lethal stand-replacing fires that were infrequent and at intervals of approximately 140–350 years. The mixed-severity fires occurred on lower elevation drier valley areas that are more gently sloping or flat in topography. The latter occurred at higher elevation with more rugged, steeper topographies. In the last 100 years, fire suppression may have changed this to the detriment of the mixture which is fire-dependent, comprising early- to mid-seral species. With no fire, overstocking can lead to greater mortality from insects and disease and to species replacement with the more mesic-loving shade-tolerant subalpine fir, Engelmann spruce, and Douglas-fir.



Box 9.3 Figure 1 A seed-tree cut for western larch and lodgepole pine. This example shows a seed tree in the foreground for western larch (8 seed trees/acre, 20/ha) in which the site preparation included chipping the coarser material and distributing the branches but it was not burned. This encouraged some germination of lodgepole and with more larch from the nearby seed trees. In the background is a true clearcut where the same site treatment was applied. Much of the larch seed that germinated came from the adjacent seed trees that were downwind. *Source:* Mark S. Ashton.

Regeneration

Regeneration methods for lodgepole pine (true clearcuts) and western larch (seed tree) can be integrated across the landscape to reflect both lethal and sub-lethal stand-replacing fires which would have regenerated these two species on the steeper slopes. Seed-tree cuts for western larch include regeneration of fire-intolerant and well-dispersed seeds of pioneers like lodgepole but focus on larch because of its poor seed dispersal (Fig. 1). Integrated stands across the slope can create a mosaic of true clearcuts and seed-tree methods within which stands along riparian zones and seeps are protected, imitating in a more logistically feasible way a stand-replacing fire across the landscape that varied in severity.

severe fires in the north. Abrupt declines in fire frequency in about 1900 from fire suppression and grazing, dramatically influenced patterns in recruitment and regeneration (Belsky and Blumenthal, 1997). Ponderosa pine, in particular, and mixed conifer forests more generally, have undergone large compositional and structural changes that have often led to overstocking. There were subsequent declines in forest health, and changes in fire regimes from ones that were frequent, patchy, and at the groundstory, to ones that are more widespread, with lethal crown fires.

Many of the fire-tolerant conifers, particularly ponderosa pine and western larch, require pre-site treatment fires, masting, and favorable post-seeding rains, all to sequentially coincide (Fig. 9.2b; Box 9.3). The seed-tree method of regeneration is appropriate for such species on the more exposed southern and eastern aspects and higher elevations in the northern regions, and the more sheltered northern and western aspects toward the lower elevations and hotter climates of the south. Regeneration requires site treatments that scarify and expose the mineral soil during the seeding cut. In cases where understory encroachment has occurred with more shade-tolerant, fire-sensitive species, such as Douglas-fir or white fir, preparatory cuts resembling heavy low thinning need be done several years prior to a seeding cut.

Seed-Tree Methods in the Oak–Hickory Forests of the Northeast and Midwest

An extensive literature on the land use of Native Americans suggest that the strong presence of mast-producing trees (e.g., oaks, pines, hickories) is evidence of human fire management and swidden agriculture within forests. Fire is suggested to have been used as a management tool starting around 6000 BCE and swidden farming was at its peak in 1000 BCE (Delcourt and Delcourt, 2004). Oak–hickory and pitch pine–white pine pre-settlement forests of the northeast and central states of the US are suggested to be the signatures of the use of fire and agriculture. These forest types were dominant where pre-European agriculture was intensively practiced in the valleys of the upper Mississippi and its major tributaries, as well as the coastal lowlands and plains of the east coast. The eastern uplands are thought to have been burned to maintain the oaks and hickories for fall nut harvests, for hunting game, and collecting berries.

After colonization and clearance of forests for agriculture, the use of fire was both more extensive and more permanent in nature (Crow, 1988; Orwig and Abrams, 1994; Foster, Motzkin, and Slater, 1998). The current abundance of oak and hickory in the northeastern upland forest is therefore closely tied to this past land-use history of disturbance. Frequent fires and heavy cutting favored oak, chestnut, and hickory because of their ability to sprout; their rootstocks can withstand creeping groundstory fires, which their more shade-tolerant competitors, such as black birch, tulip-poplar, and the maples, could not tolerate (Abrams, 1992; Abrams and Nowacki, 1992). Interestingly, the red oaks predominate on the wetter eastern side of the Appalachians and southern New England while the white oaks predominate in the drier continental regions of the Midwest. Both oak sections (and formerly chestnut) are aggressive colonizers of open habitats as long as there is a nearby seed source, a dispersal agent, and little to no competition from moisture-loving, shade-tolerant tree species. Traditionally, oak and hickory has been regenerated naturally with the use of shelterwoods (see Chapter 10). This makes sense where oak can establish and remain in the understory as advance reproduction, but where it cannot establish because of shade and competition from more mesic-loving species, seed-tree systems are more appropriate. Examples are where second-growth oak forests that have regenerated on mesic sites now face regeneration issues. Many are transitioning to maple, tulip-poplar, and black birch forests because of a lack of sub-lethal disturbance. Site scarification is needed at the time of a seed cutting to promote the oak and hickory. This can be followed after oak and hickory establishment by prescribed fire to kill the thin-barked birch, maple, and poplar. The cutting itself needs to be timed to a satisfactory mast year. Only 10–12 large-crowned dominant oaks of 16 in (40 cm) DBH need to be kept at a uniform spacing of 60–70 ft (18–21 m) (Box 9.4).

Seed-Tree Methods in Tropical Forest Regions

Tropical forests have not been previously thought of as suited to the seed-tree regeneration method until closer examination showed that it has been widely practiced, but under a different name and process. Silvicultural systems of indigenous forest peoples across a wide variety of tropical climates practice swidden agriculture, much like peoples of pre-settlement North America and Europe. Many of these systems reflect the same site treatments and careful planning as a seed-tree regeneration method (Peters, 2000). They can be regarded as managed fallows that start with forest clearance in a large patch with individually spaced trees of economic importance selected to be left standing. Leaving specific trees standing is intended to facilitate their regeneration and enrich the new forest with more desirable species after crop cultivation has ceased. Site treatments are focused toward crop cultivation that is conducted the first few years after

Box 9.4 Ancient oak woodlands and wood pastures.

Introduction

Holm oak (*Quercus ilex*) across the Mediterranean, and sessile (*Q. petraea*) and white oak (*Q. robor*) across central and northwestern Europe were a very important food source for open-range livestock during the medieval period (Pulido and Diaz, 2005). They were cultivated as wood pastures. Open-grown trees provided acorn mast that was beaten down to fatten livestock. In some areas of Spain and Portugal, the "Dehesa" system is still a viable practice. Many small enterprises are starting both in Europe and the US that are emulating this system to produce high-quality pork.

Regeneration

The white oaks as a section are shade intolerant, masting with heavy seeds that are largely dispersed by caching birds and mammals, in most cases near the parent tree (Pulido and Diaz, 2005). Many acorns can be buried by the

(a)

(b)

(c)

Box 9.4 Figure 1 **(a)** *An example of what pigs can do to the soil as a site treatment if used carefully and for only a period of time. If left for a long period, serious damage can be done to the tree root systems.* *Source:* S. Cox. Reproduced with permission from S. Cox. (b) *A medieval illustration of beating the tree canopy to drop acorns to the pigs below.* *Source:* British Library. (c) *An example of an old white oak wood pasture that had the understory burned repeatedly.* *Source:* Mark S. Ashton.

Box 9.4 (Continued)

Box 9.4 Figure 2 An example of a seed-tree cut for red and white oak in southern New England. The harvest was done in the fall. The slash has been chopped and crushed to the ground and where possible logging machinery has scarified the soil to help bury the acorns. In this photograph there are occasional reserves of small-diameter sugar maple. *Source:* Mark S. Ashton.

over the soil. When acorns germinate, seedlings require high light environments without competition from more shade-tolerant species. The site disturbance by pigs eliminates most competition (Fig. 1a). Fire was another tool used by people to maintain the openness and herbaceous forage beneath the oak. This also eliminates shade-tolerant tree species recruitment but promotes oak old-growth forests originated after wood pastures in Europe, and swidden agricultural fields in eastern North America, were abandoned.

Seed-tree cutting of oak on fertile soils that chops and crushes the slash and scarifies the soil at the time of a mast year is a satisfactory way of securing many species of oak – especially white and chestnut oaks (Fig. 2).

clearance. The first treatment includes prescribed broadcast burning of the residual slash to produce a nutrient flush for crops and to increase mobility for tending and access. This is followed by scarification and weeding to eliminate undesirable vegetation. Young germinants and seedlings from the seed trees are protected during crop cultivation (Box 9.5).

These systems tend to simplify the original forest composition and structure to those species desired for their products, both timber and non-timber (latexes, fruits, medicinals, cordage, etc.). Like seed-tree systems, the species that regenerate well are: (1) the short-lived fast-growing pioneers of the initiation stage that are dispersed by small birds and bats and would come in as seed rain without nearby seed trees, and (2) the focal species of the method itself that would be considered the long-lived pioneers or canopy-dominant/late-successional species that are shade intolerant, masting, and with poor seed dispersal. Many economically important tropical tree species fall into this category (e.g., the mahogany family) and yet western models of tropical silviculture have continued to try to regenerate these trees through modified selection systems (see Chapter 13). There is plenty of documented evidence that selection systems do not work for these kinds of tree species (Fredericksen and Putz, 2003; Ashton and Hall, 2011). However, seed-tree cuts are beginning to be used in Quintana Roo, Mexico (Negreros-Castillo *et al.*, 2014).

Box 9.5 The mahoganies (Meliaceae).

Introduction

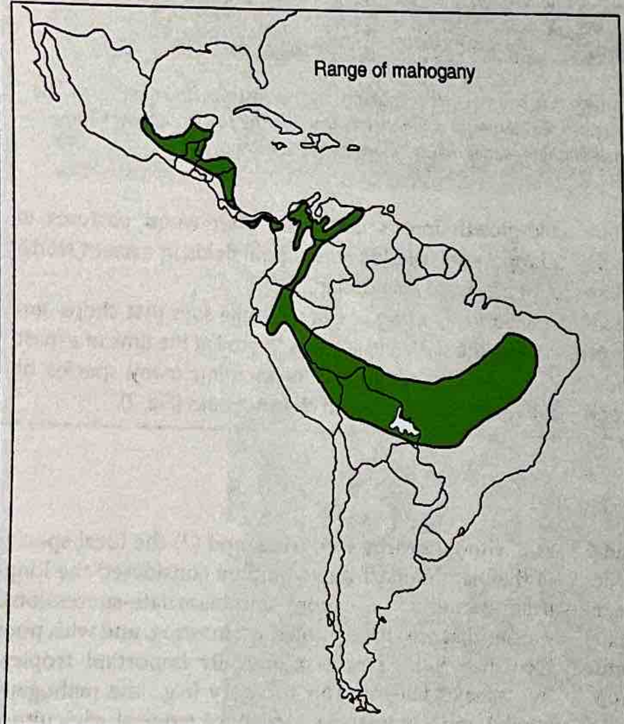
The mahogany family (Meliaceae) comprise many genera across the seasonal evergreen rainforest regions of the tropics. *Swietenia* and *Cedrela* are the two main timber tree genera in Latin America. *Entandrophragma* and *Khaya* are the timber genera of west and central Africa. *Toona* is the genus in Indo-China. All are shade-intolerant long-lived pioneers that get to large sizes within the forest as emergent canopy trees. They require considerable disturbance in order for their germination and growth to compete above their much more shade-tolerant associates. In addition, they are masting species that disperse seeds from capsules that do not travel more than 300 ft (100 m) away from the parent tree. Finally, most of these species are site restricted, often to richer lower-lying soils of topographies that are not noticeably changing. Many studies have examined these genera and wondered how such large trees attain the canopy, but are not easily recruited from beneath.

Strong historical evidence suggests that mahogany does well within swidden cultivation that is associated with fertile soils, and it does well in post-hurricane environments, including fire, and in post-flooding events. All of these disturbances are sub-lethal or lethal for most of the rainforest vegetation except mahogany, which, if the trees survive, can disperse their seed into the openings that are free of competing vegetation. They are strongly episodic at timescales of at least 50 years and in many cases more.

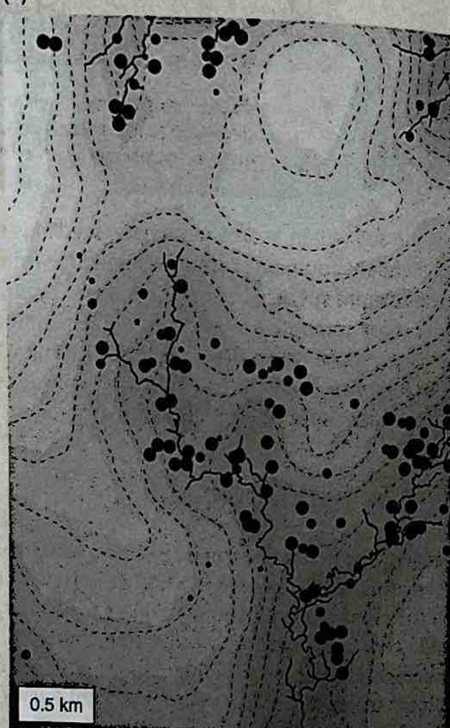
Regeneration

Swietenia macrophylla (big-leaf mahogany) is the most important timber tree in the Meliaceae family within Latin America. Its distribution reflects that of many timber species in the family. It is associated with the more seasonal climates of the Latin American tropics (Fig. 1a) and has a landscape-scale distribution pattern that is restricted to the lower-lying more fertile soils (Fig. 1b). The natural method

(a)



(b)



Tree diameter: • 20–30 cm ● 30–60 cm ● >60 cm — Seasonal streams - - - 2-m Contours

Box 9.5 Figure 1 **(a)** Historical range of big-leaf mahogany in the Americas. *Source:* Adapted from Martinez *et al.*, 2008. **(b)** The distribution of big-leaf mahogany in a 1000 ha (~2500 acre) plot in Para, Eastern Amazonia, Brazil. *Source:* J. Grogan. Reproduced with permission from J. Grogan.

Box 9.5 (Continued)

of regeneration for these trees is by seed-tree cutting. Stands should be delineated by mahogany's restricted landscape distribution patterns and subdivided to accommodate a management regime for a sustained continuous yield. Most of the forest is therefore left untouched, or managed for other products and services. The mahogany stands should be on a sequential rotation. Of course, this never happens. Almost every timber tree in the Meliaceae both in Africa and Latin America is "managed" using diameter-limit logging where all trees greater than 50–60 cm (20–24 in) DBH are cut. There are regulations about reserving some as seed trees but they are not enough, and the environment within which a seed has to germinate and grow, is completely incompatible with its autecology.

Box 9.5 Figure 2 A Milpa swidden, cleared within the rainforest of the Yucatan, Mexico and cultivated with beans, corn, and squash and subsequently abandoned. It is a perfect site for mahogany to regenerate if there is a nearby seed source as seen by the tree in the background. *Source:* J. Grogan. Reproduced with permission from J. Grogan.

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