8

Natural Regeneration: The Clearcutting Method

Introduction

The **clearcut method** deals with forest stands that originate as a single age class that have been established following a complete harvest and site treatment that creates a lethal disturbance. This is defined in silviculture as a **clearcut**. A variation in the clearcut method is called clearcut with reserves, which retains individual trees, intact patches, and other forest structures within a clearcut stand (see Chapter 11 for a more detailed description). The clearcut method is also called **true clearcutting.**

Single-species, uniform-sized, even-aged stands regenerated by **true clearcutting** are the kind that are best understood and simplest to manage. They start with growing spaces that are almost completely free of trees and most other potentially competing vegetation. Clearcutting mimics the most lethal of natural disturbance regimes that can occur to the site (e.g., very hot forest fires). Site treatments that accompany true clearcutting are some of the most intensive manipulations to the groundstory to both eradicate existing vegetation, and to prepare the ground surface as a suitable seedbed and microenvironment for new regeneration. Seeds germinate and seedlings establish *after* the regenerative disturbance, usually within a very short period of years, and the new trees all grow up together in a single cohort. The development of the stand is so uniform that the even-aged yield tables that are discussed in connection with thinning, can be used to predict their development. Species that regenerate by this mode are pioneers that are very shade-intolerant, small-seeded, fast-growing, and early- to mid-successional species.

Pure even-aged stands usually persist only where the site conditions are so difficult that only one or two tree species can endure the environmental extremes of sites that are too dry, too wet, too cold, or too hot. Regional examples where forest types are pre-adapted to lethal disturbances, and where true clearcutting might recreate such disturbance can be found in the Intermountain West, the pinelands of the southeastern US, and the interior fire-prone boreal of Canada (Table 8.1). On better sites, severe disturbance can create conditions during the next establishment period that may be favorable to only one hardy species. On other sites, some pest or damaging agent may allow only one species to persist. It is also possible to create such stands by silvicultural treatment, although it is not necessarily easy to maintain them. On fertile moist sites in climates that are more moderate, true clearcutting may open the way for invasions by jungles of mixed species, often including invasive species that are virtually impossible to control.

Creating the necessary conditions for establishment requires intensive site-preparation measures such as those described in Chapter 7, and good knowledge that there is an adequate and abundant seed source of desired pioneers that can colonize the new open area quickly and completely.

The Protocol

The clearcut regeneration method involves only one cut.

Clearcutting: this cut removes the entire canopy of the stand, leaving maximum growing space. Site preparation is usually associated with the harvest, in order to create conditions for newly established seed germination and seedling development.

Misuse of the Term Clearcutting

It might seem that the word "clearcut" would be completely understood, but it is used in ways that have very different meanings to different people. As a technical term of silviculture, clearcutting refers to treatments in which virtually all trees and other vegetation are removed, and almost all of the growing space becomes available for new plants. Timber harvesting alone is usually not sufficient to achieve a complete removal of vegetation; that is one of the main roles of the site-preparation measures that were described in Chapter 7. If this kind of clearcutting is meant, it should be referred to as: **true clearcutting, the clearcut method, silvicultural clearcutting,** or **complete clearcutting**; sometimes the term **clean cutting** is used, from the British usage.

The Practice of Silviculture: Applied Forest Ecology, Tenth Edition. Mark S. Ashton and Matthew J. Kelty.

Table 8.1 Examples of the natural disturbance regimes of forest types and the species that can be regenerated by true clearcutting in North America.

Region and species/ forest type	Disturbance regime and return interval
Interior boreal	
Jack pine	Fire return intervals for jack pine vary between 5–50 years. Severe stand-replacing fires are on the better soils with longer return intervals. The poorest soils have frequent intervals promoting a pine barren. The cones exhibit serotiny and require fire for release of seed and germination on mineral soils
Black spruce	Like jack pine, the species spruce regenerates from cone-stored seed after a fire. However, spruce is restricted to acidic organic bogs. Nearly all stands are replaced by fire at 50- to 150-year intervals. Areas that have burned create a complex mosaic with unburned areas. Periodic extreme summer droughts promote larger and more lethal fire events
Pacific Northwest	
Douglas-fir	Douglas-fir with its thick bark is the most fire-hardy tree of the Pacific Northwest where it co-exists with a group of more shade-tolerant and mesic-loving species. Douglas-firs that survive catastrophic stand-replacing fires that can occur every 500–1000 years germinate well on mineral soil. Seeds require a good mast year and a nearby seed source for quick establishment and stocking
Red alder	This wind-dispersed prolific seeder regenerates on moist sites, especially along riparian zones. It is a strong competitor of Douglas-fir in such areas. It regenerates from riparian flooding events on new sandy deposits or after fires that expose new growing space and mineral soil
Intermountain	
Lodgepole pine	The accumulation of fuels, insects, and climate, all interact to regenerate lodgepole pine in stand-replacing fires. However, these fires can form a mosaic; only in parts of its range does it exhibit serotiny and an ability to regenerate after hot fires. Lodgepole pine regenerates in monodominant stands at intervals of about 80–100 years. Stands can vary in stocking from open grown to very dense
Engelmann spruce/ subalpine fir	Both subalpine fir and Engelmann spruce are fire-sensitive, long-lived species at high elevation, easily killed in catastrophic wildfires that occur about every 150–400 years. These fires burn unevenly with pockets of trees surviving and serving as a seed source. Germinants require mineral soil but can take many years to establish within thick herbaceous vegetation that erupts after a fire
Middle west	
Eastern cottonwood	The shade-intolerant cottonwood, with wind- or water-dispersed seeds, colonizes new floodplains, deltas, and sandbars after severe flooding events of large river systems
Gulf Coast/southeast coastal plain	
Slash pine/longleaf pine	Mature slash and longleaf pine are fire resistant. Fire return intervals are 5–30 years with groundstory burns, and are generally not stand replacing. Seed is produced during mast years and is dispersed effectively over ~300 ft (100 m) from a parent tree. Clearcutting in small areas can be effectively done, but seed-tree and other two- to three-aged (multi-aged) methods are more reflective of the actual regeneration cycle
Loblolly pine/shortleaf pine	Loblolly and shortleaf are less fire resistant than slash or longleaf but have similar attributes. Low-severity spring burns that expose mineral soil before seedfall is the most satisfactory way of regenerating loblolly. In a large part of its range, it is the most shade-intolerant and fire-hardy species compared with its more mesic-loving shade-tolerant hardwood associates
Northern hardwood	
Paper birch	Paper birch is a prolific producer of light-weight, wind-dispersed seed that requires mineral soil to colonize stand-replacing disturbances such as fire and landslides
Pin cherry/black cherry	Many cherry species regenerate after stand-replacing disturbances from the soil seed bank. Both pin and black cherry are shade-intolerants, relative to their associates (sugar maple/beech). Fire return intervals are long (500–1000 years) and are stand replacing, greatly favoring cherry from the seed bank to the complete exclusion of other species, which are all fire sensitive

Source: Mark S. Ashton.

The main problem with the term clearcutting is that it is often used to describe logging operations in which only the merchantable trees are cut. These operations are often called a **commercial clearcut**. The problem arises when these kinds of logging operations are simply called "clearcutting". They have no connection to the establishment of a new regenerating stand. Instead, they are linked only to commercial exploitation of the standing timber. However, the logging industry will likely continue to use the term for their operations. The term **true clearcutting** should be used when there may be conflicting interpretations of these terms.

There are two situations where silvicultural methods appear to be clearcutting, but are not. First, the simple coppice method (see Chapter 12) depends on vegetative sprouting, but the degree of removal of the old stand very much resembles clearcutting. The difference is that the roots and stems are left alive as the source of vegetative sprouts for the next coppice stand. Second, there are situations where mature forest stands grow above advance-growth seedlings and saplings. Removing the overstory would appear to be a clearcut method, but the regeneration is left to grow. The use of the term **one-cut shelterwood** (discussed in Chapter 10) has the virtue of focusing attention on the source of the regeneration, and is the more appropriate term to use if keeping to the proper silvicultural terminology of this book.

Regeneration of Pure Stands from Natural Seeding

True clearcutting exposes the site so much that it is compatible with natural (or artificial) seeding, only when the species are capable of enduring full exposure to mineral soil and sun. Thus, it is not suitable for certain shade-tolerant/exposure-intolerant species unless they are planted (and sometimes not even then). However, this attribute of clearcutting can be of some advantage if the goal is to encourage species of early-successional status and discourage seed regeneration of shade-tolerant species that happen to be undesirable.

The prospect of success with natural regeneration after clearcutting, and the ways of securing it, vary widely depending on the source and means of dispersal of the seeds. These distinctions are so important that each will be considered separately here.

Clearcutting with Seeding from Adjacent Stands

Sometimes it is possible to clearcut a stand and depend on the seeds that are dispersed from a nearby untreated stand to provide the regeneration. With such an approach, the type of dispersal is all-important. In the temperate zone, the pioneer species that are best adapted to this kind of silviculture are disseminated by wind. In the tropics, where it is less windy, small birds and bats may play a more important role, but there are still a number of wind-dispersed pioneer tree species such as Honduran mahogany. There are even species of river flood-plains, such as the tupelo gums of the bottomlands of the southeast, that can be regenerated after clearcutting by floating seeds.

Wind, water, and animals can carry a few seeds over very long distances. However, in regenerating forests, it is usually necessary to remember that the density of seeds deposited on a unit of ground surface varies inversely as some power of the distance from the source. The rest of this discussion about dispersal of seed into clearcut areas involves wind, but some of the same ideas may apply to other types of dissemination, and examples will be provided of other dispersal modes.

Wind-dispersed seeds usually have wings, and moving air is usually turbulent enough that some seeds are lifted aloft rather than dropping only downward after being released from the cones or fruits. Where surrounding trees are the only source of seed, the clearcut area must be sufficiently small (usually long and narrow) to allow for adequate dissemination to all points. Safe widths for clearings to be stocked by wind-disseminated seed can range from one to six times the height of the adjacent timber from which seed will be dispersed, and depending on the size and weights of the various species. The normal direction of the prevailing wind during the season of seed dispersal should be known, and the clearing should be located so that its long axis is perpendicular to this direction. Unless the clearcut area is very narrow, the distribution of regeneration is likely to be uneven. Models demonstrate that to predict where wind-dispersed seeds will land, it is important to know the parent tree source in the adjacent forest, the prevailing winds at time of seed dispersal, and the seed mass. Knowing these factors, the great majority of seed is dispersed no further than a few tree heights from the edge of the adjacent forest (Greene and Johnson, 1996) (Fig. 8.1).

Most dissemination occurs during dry, sunny weather when the winds are brisk and gusty. The most effective winds are frequently those that blow the dry interior regions of continents, but they are not necessarily of the same direction as the prevailing winds. In terrain with rugged topography, it is best to have the long axis of the clearcut opening run perpendicular to the contour lines, because the winds responsible for dispersal of seeds are usually altered in direction so that they blow up or down valleys. An example would be the seed dispersal of western larch on the midslopes of the interior valleys of the northern and central Rockies (Schmidt, Shearer, and Roe, 1976). The seed source needs to be downslope of the area to be regenerated, so that seasonal dry winds that come from the valleys are effective. The width of the clearcut areas is often restricted by distances of effective seed dispersal. Various research has shown how the control over the width of openings can determine whether

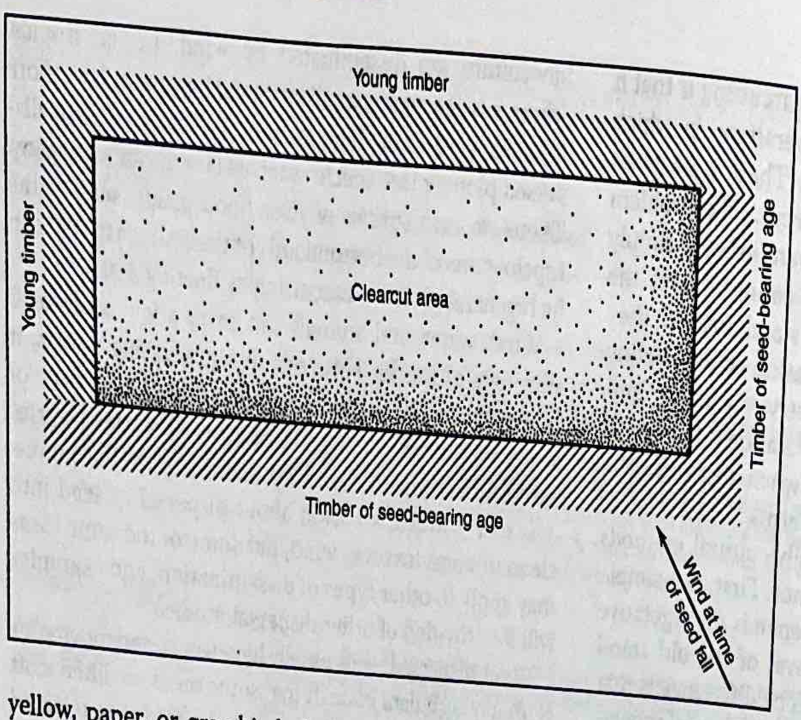


Figure 8.1 Seed dispersal patterns within a clearcut opening. Source: Mark S. Ashton.

yellow, paper, or gray birch dominates regeneration in some northern hardwood forests (Marquis, 1966; Smith and Ashton, 1993; Liptzin and Ashton, 1999).

As will be described in Chapter 9, the difficulties of producing seed dispersal over long distances can be mitigated by reserving individual trees, uncut strips, or groups of trees as sources of seed within the clearcut area.

Landscape Scale Patterns of Operation

Substantial research has demonstrated that true clearcutting as a silvicultural natural regeneration method is a sound method for the right circumstance and species (Isaac, 1943; Wahlenberg, 1965; Marquis, 1966; Schmidt, Shearer, and Roe, 1976; Lotan and Perry, 1983; Safford, 1983; Chrosciewicz, 1990). However, the scale and arrangement of stands at which it is applied is a problem, and there are many examples of inappropriate use. The major issues around clearcutting can be categorized as low aesthetic and amenity values, high fragmentation of the original forest structure and interior forest habitat, and increased proneness to windthrow, fire, and landslides. Such issues can be mitigated by careful planning in time and space.

First, there is growing evidence that any attempt to recreate the scale and intensity of natural disturbances with clearcuts, needs to consider the pattern and amount of variability in edge, opening sizes, and woody debris structures (Niemela, 1999; Cissel, Swanson and Weisberg, 1999; Niklasson and Granstrom, 2000; Bergeron *et al.*, 2002). Much of this work has been done in the Canadian boreal and the US northwest, matching clearcutting arrangement, site treatment, and timing, with known natural patterns of fire size, intensity, and return interval (Cissel, Swanson and Weisberg, 1999; Bergeron *et al.*, 2002).

Second, spatial modeling tools can be used to quantify landscape-scale structures and patterns into indices that can then be used to assess proposed landscape-scale cutting operations (Haines-Young and Chopping, 1996). For example, Li *et al.* (1993) showed from simulations that aggregating and creating larger stands for clearcut applications was preferential in reducing edge and forest fragmentation, and in so doing, created higher wind firmness and more interior forest structure for certain wildlife.

Third, natural disturbances that are large can often have wide ranges of stocking, with some areas failing to regenerate or taking many years to recover. To overcome seed dispersal limitations, when stands are purposely large, adequate seed dispersal can be achieved by sequential or alternate cutting of the stand that is completed over a short period of time (e.g., 2–3 years) (Fig. 8.2). The alternate strips of trees within the stand act as a nearby seed source to regenerate the opening and technically are a temporary source of seed within the stand. Such an operation allows a clearcut to emulate the scale and intensity of a natural disturbance, but more predictably secure an even distribution of regeneration to meet commercial demands of establishing a new crop quickly, mitigating any detrimental erosion effects from unoccupied growing space, and meeting green-up regulations.

Site Treatments Associated with Seeding from Adjacent Stands

As previously stated, treatments associated with true clearcutting that prepare the soil surface for seed that are dispersed from outside the stand, are considered lethal. They are some of the most severe site treatments that accompany a regeneration method. In most cases, particularly where there is no fiber or biomass market, slash residue from the harvest can be broadcast burned to simulate a more controlled condition of a wildfire that prepares the seedbed for regeneration. Such burns can still pose a risk of escape, so pile-and-burning is an even more controlled alternative, particularly when piles are burned during the wet or cold period of the year (see Chapter 7 for details) (Table 8.2). The purpose of both kinds of burning is to expose mineral soil for best

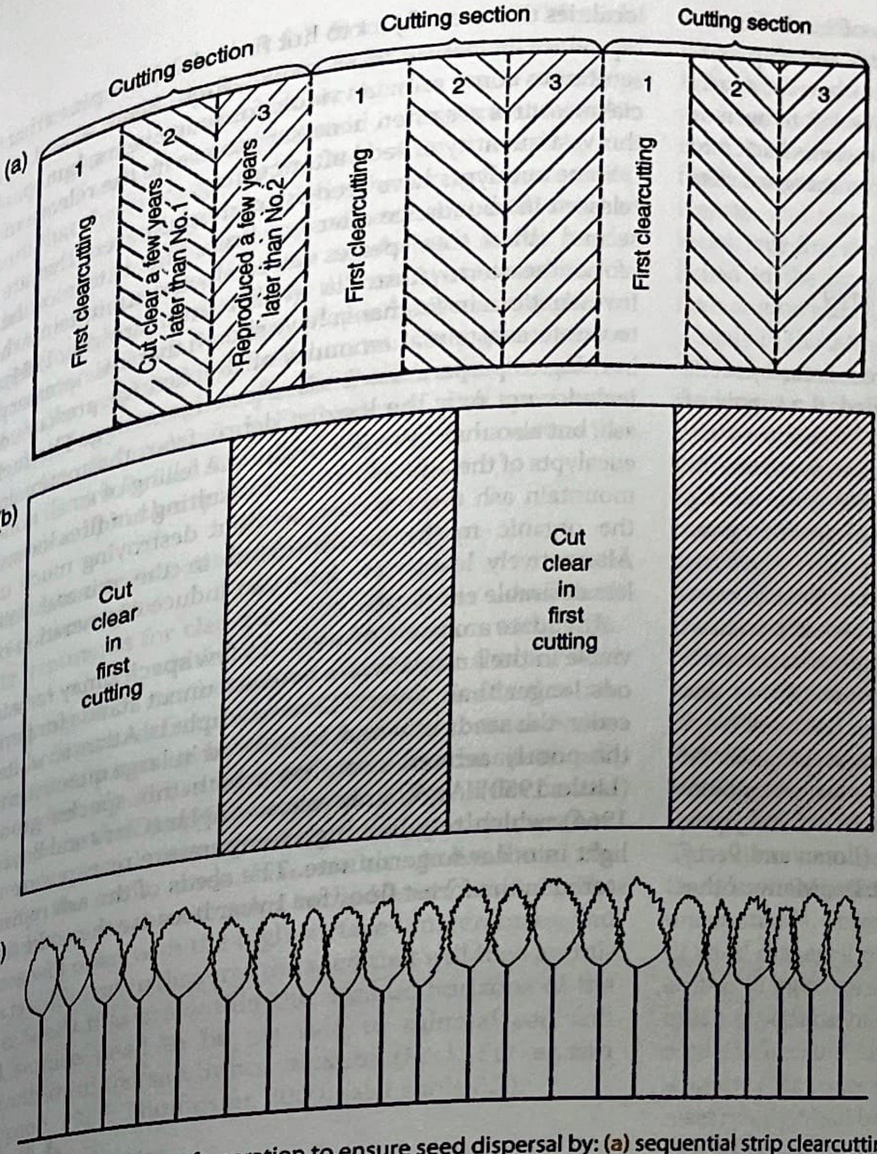


Figure 8.2 The pattern of operation to ensure seed dispersal by: (a) sequential strip clearcutting; or (b) alternate clearcutting of a stand. (c) A profile of stand development post clearcutting, showing the small difference in height due to regeneration lag of the strips that were cut last. *Source:* (a–c) Yale School of Forestry and Environmental Studies.

Table 8.2 Site treatments that are often used with true clearcutting.

Treatment	Example
Surface soil preparation	
Usually several treatments are done in combination with each other to be most effective	Pile and burning Chopping and crushing Broadcast burning Root raking and scarification Windrowing Disking and bedding
Reducing competition	
	Broadcast foliar application of herbicide Prescribed groundstory fire

Source: Mark S. Ashton.

germination of light-seed species. After pile-and-burning, some additional scarification or use of herbicide for vegetation control may be needed.

Where fire cannot be used because of air-quality or wildfire-risk concerns, the alternatives are few and often less desirable. Piles can be left unburned, scarification can be done, and/or broadcast application of herbicides can be used to control residual sprouting or seedbank vegetation.

Where natural disturbances are less severe, desired site preparation can be less intensive. The combined use of herbicides and scarification in these cases can be the most effective site treatments. An example is the coastal plains and uplands of the southern US where natural fires are more frequent but less severe as compared to certain interior boreal or intermountain areas.

A concern for many of these kinds of intensive site treatments where there are strong energy and chip markets for woody biomass, is the desire to harvest nearly the entire site such that there is no debris left to burn or to rot in place and return carbon and nutrients back into the soil. Temptation to use everything on marginal sites needs to be avoided at all costs.

Clearcutting with Regeneration from Seed on the Site

The restrictions set on the size of clearcut areas by seed-dispersal distances can clearly be avoided, if a supply of seed is stored on the trees or in the soil. With almost any species, a substantial amount of seed may come from the trees removed in clearcutting, provided that the cutting is made just before or after the release of seed in a good seed year.

With most species, the only seed from the cut trees that is useful for regeneration is that which is produced in the current year. Among the exceptions are certain conifers that have stored seed in serotinous cones that open gradually over a period of years, as is true of black spruce, or that rarely open to any extent except under the influence of high temperatures. The most prominent species in the latter group are the jack and lodgepole pines of the northern US and Canada (Lotan and Perry, 1983; Chrosciewicz, 1990) (Fig. 8.3). Many other localities that are subject to hot fires also have pines that reproduce in nature after crown fires. Seed stored in serotinous cones remains viable for many years, but special measures are often necessary to create the release of this vast quantity of seed after cutting.

Some eucalypts have seeds stored on the trees that are released in abundance after hot fires. This is true of the second tallest tree species on earth, the mountain ash of southeastern Australia (Hillis and Brown, 1984). Investigations in Tasmania have shown that it is necessary to create substantial amounts of dry fuel for prescribed burning to prepare seedbeds after clearcutting. The fuel includes not only the logging debris from the mountain ash, but also that from the deliberate felling of small non-eucalypts of the understory. The resulting hot fires induce mountain ash regeneration without destroying much of the organic matter incorporated in the mineral soil. Alternatively, less severe fires can induce regeneration of less desirable eucalypts.

Adequate amounts of seed of a few species may remain viable in the humus layers beneath uncut stands for periods longer than 1 year. One example is Atlantic white-cedar, the seeds of which are stored in large quantities in the poorly aerated peats on which this species grows (Little, 1950). Another is yellow-poplar (Clark and Boyce, 1964), which requires high temperature or exposure to light in order to germinate. The seeds of the ash remain stored in the forest floor for 1 year because they take that

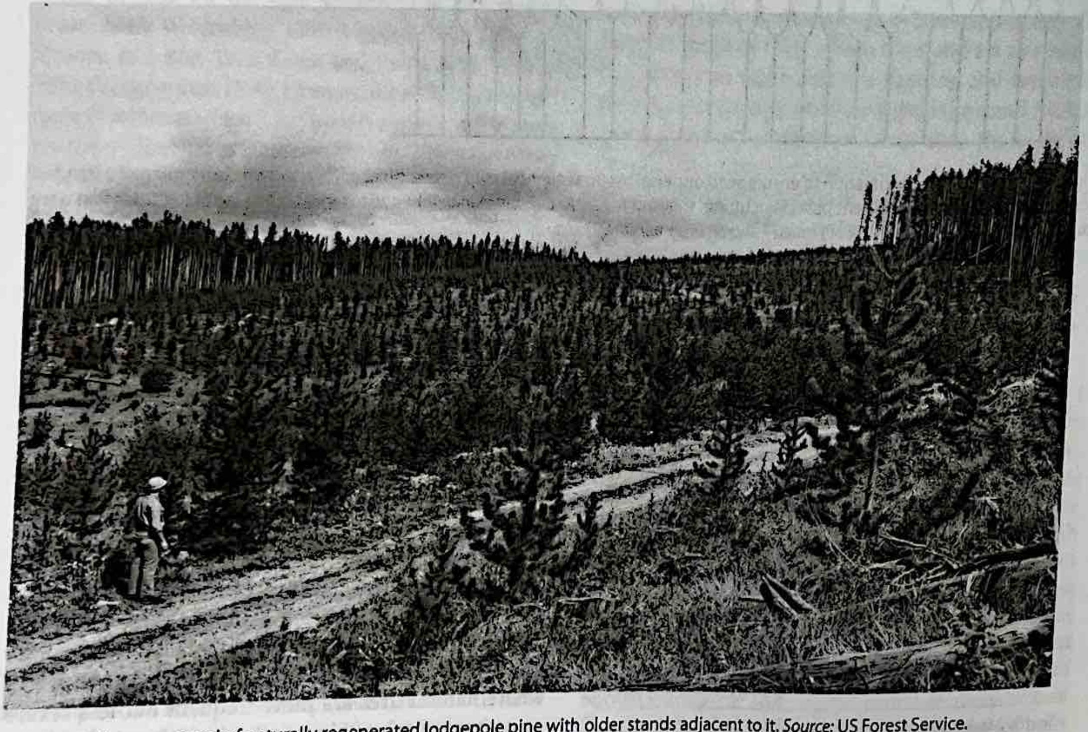


Figure 8.3 A young stand of naturally regenerated lodgepole pine with older stands adjacent to it. *Source:* US Forest Service.

long to mature after they fall from the trees. With such species, it is often possible to expect seemingly miraculous regeneration after removing the entire standing source of seed. However, it would be important to make sure that the seeds are on the site before proceeding.

Long-term storage of seeds in the forest floor is more characteristic of pioneer trees, annuals, and shrubs. Many of these species have seeds with hard, nearly impermeable coats that allow the embryos to survive for the many decades that may elapse between major fires or similar regenerative disturbances. They germinate or flourish long enough to produce seeds and then die or lapse into the understory. Examples of such species are in the genera *Rubus*, *Ribes*, and *Ceanothus*, as well as the short-lived pin cherry.

Site Treatments Associated with Regeneration of Seed on the Site

Site treatments for clearcuts that rely upon a seed bank or seed source within the forest floor or within the remaining slash, can be treated similarly to that for seed that is dispersed from adjacent stands. Seeds that are within serotinous cones should have the branches distributed evenly across the stand, and then the site should be broadcast burned (Chrosciewicz, 1990). If fire cannot be used, a useful alternative is to first pile the branches, scarify the soils, and then evenly redistribute the branches across the site prior to the heat of summer. The cones will open with the high surface temperatures, and this is sufficient to disperse the seed that will then germinate. Seeds that are within the organic horizons of the soil surface need to be exposed to mineral soil and warmth from the sun by scarification (Leck, Parker, and Simpson, 1989; Thompson, 2000) (see Table 8.2).

Applications of True Clearcutting: Case Studies from North America

West Coast Douglas-Fir Region

The most common criterion of adaptability to clearcutting is the capacity of a species to grow faster in height than the undesirable competitors. This is why clearcutting is not well suited to those kinds of shade-tolerant species that grow slowly in the juvenile stages. The pioneer vegetation (which includes the desired trees species) grows so much faster than the shade-tolerant species that it would require a great deal of release work to maintain them in the rapid vegetation growth.

The evolution of silviculture in the west coast Douglas-fir region provides a good illustration of the development of the silviculture of pure even-aged stands. Historically, under entirely natural conditions, coastal Douglas-fir often regenerated after lightning fires. The sources of seeds were scattered seed trees or patches of trees in swales that escaped fires or were not promptly killed by them. Douglas-fir, which is normally the fastest growing conifer of these forests, tended to dominate for the first century of stand development. The Douglas-firs then dwindled from the attrition of various root-rots and insects, and were gradually replaced by western hemlocks, true firs, and western redcedar that became established in the understories at the time of the initiating fires or afterwards.

Early in the 20th century, these forests were being liquidated by railroad logging in combination with cable yarding. As a result, clearcut areas were extended progressively along the logging railroads. Even though only the best trees were harvested, the shifting of the yarding cables usually pulled over the rest of the trees, creating huge volumes of slash. Society at that time had no concern for forest regeneration, but it did have the hope that laws requiring broadcast burning of slash might reduce the dangerous wildfires of the time.

Foresters had little to say about what was going on, and even at that, tended to be complacent about the very large size of the clearcut areas. There was the mistaken view that the seeds of Douglas-fir from the old stands would remain stored and viable in the forest floor for many years, even with clearcutting and slash burning. This view was based on the observation of the fine Douglas-fir regeneration that had appeared after fires in uncut stands. Foresters had discounted the importance of wind dispersal of seeds from adjacent stands or from scattered survivors. They did correctly perceive that a quick repetition of tree-killing fires would eliminate the conifers because the seed supply would be destroyed, whatever its source. Unfortunately, the otherwise good research that had been done about the regeneration process had omitted any good test of the long-term viability of Douglas-fir seeds.

By the 1930s, it was shown (Isaac, 1943) that retention of living seed sources was crucial. Foresters began to have some modest influence on harvesting practices, and interest arose in regeneration provided that it cost little. For the first time there were tractors and trucks powerful enough to move the huge old-growth trees that could previously be logged only with cumbersome steam-driven machines. However, only the biggest and best trees had enough value to be harvested.

These circumstances set the stage for ill-fated efforts to prolong the lives of old-growth stands by light partial cuttings referred to as "selective logging." The cuttings were intended to operate as selection cuttings to create uneven-aged stands (Curtis, 1998). The only trees cut were commonly those roughly 3 ft in diameter (1 m); these were mostly the scattered surviving Douglas-fir, which in spite of their great size and age, were still the most durable trees in the old stands. Unfortunately, most of the remaining trees were western hemlocks and true firs. The usual result was an acceleration of the process by which wind, fungi, and bark beetles break up ancient stands. By the 1950s, the whole episode was recognized as a fiasco to be quietly forgotten.

During the next phase, clearcutting returned to fashion. By then it had been found, at least on the most common kinds of sites such as those in western Washington, that reasonably good natural regeneration could be obtained from wind-borne seed, if the clearcuttings were less than about 100 acres (40 ha) in size. It was also found that if a few seed trees were left within the cutting areas, the regeneration was better than when reliance was placed on adjacent uncut stands.

By the 1960s, however, attitudes toward forest cutting had changed to the point that state laws required forest regeneration. The large operations with cable-logging in old-growth timber also made it desirable to clearcut areas that were too wide for natural seed dispersal. Thus, there was a period during which aerial direct seeding was a common way of regenerating after clearcutting and broadcast burning of slash.

Planting has subsequently become very common because of the willingness to invest money to ensure the prompt regeneration of properly spaced trees of the best available genetic qualities. Nevertheless, the evolution of silvicultural practice does not stop. It was soon found that the routine of clearcutting, burning, and planting was not a universal solution for the silviculture in the west coast Douglas-fir region. It tended to fail when efforts were made to extend it to sites that were either too wet or too dry.

The most complete failures were at high elevations in the Cascade Range, where there are severe microclimatic extremes, and the true firs were the main species. Plantation failures were also common on certain sites in southwestern Oregon, where the rainless summers are longer than they are farther north (Seidel, 1979). True clearcutting with site preparation often produces eruptions of red alder and undesirable shrubs when it is extended westward into the narrow coastal fringe. The fog-drip precipitation supports luxuriant stands of western hemlock and Sitka spruce, which are advance-growth species.

Another general problem associated with silviculture in the northwest in the recent past, especially on public lands, was the popular displeasure over the ugly appearance of clearcut areas. Although the use of shelterwood methods has increased somewhat, there is a remaining tendency to cling to clearcutting and planting as a standard operating procedure. Popular acceptance of plantation silviculture might be greater if it were simply limited to the numerous cases where it is essential. Currently, natural regeneration in the Douglas-fir type is less common than in any other forest type in the Pacific Northwest. The Forest Practices Act requires planting in northwest Oregon where there must be germinants the year after harvest in order to produce 3-year-old seedlings, 2 years later, something that is virtually impossible to achieve with natural regeneration. The requirements for other areas are less restrictive, but general practice is to routinely plant on all areas that are harvested. Also, the intermittent seed crops, the seed- and seedling-eating animals, and the particular susceptibility of newly germinated seedlings to extremes of heat and drought make reliance on natural regeneration too risky for areas under commercial timber production.

Southern Pines

The same sequence of events has somewhat taken place in the development of the silviculture of southern pines on the southeastern coastal plain (Williston, 1987). Initially, there was widespread devastation from the combination of land clearance and annual burning to improve grazing. Most first attempts at long-term silviculture took the form of selection cutting. These efforts proved to be fairly effective as a means of managing existing growing stocks but were not very compatible with the hardwood-control measures necessary to establish pine regeneration.

The period 1950–1970 witnessed the same quick progression from one method of establishing even-aged stands to another, mainly on industrial forests. Initially, the seed-tree method was the solution, but this method was generally replaced by aerial seeding when it was concluded that each technique required the same amount of site preparation. Then, when industrial owners became willing to spend money for prompt regeneration with well-spaced pines of good genetic qualities, planting became the common technique (Wahlenburg, 1965).

One useful illustration of the way silvicultural prescriptions should be fitted to the circumstances comes from observations in the well-watered loblolly pine stands of coastal South Carolina (Lotti, 1961). Thus it is possible for systematic programs of thinning and prescribed burning to enable natural regeneration by clearcutting throughout more than half of almost any year. The development of good seed bearers by thinning stands provides ample seed for regeneration almost annually. Regeneration is then effective if litter and understory hardwoods are sufficiently reduced by prescribed burning. Harvests between March (the time of germination) and September (when the seedling stems harden) are the exceptions; during these 7 months it is necessary to reserve seed trees to allow recovery from any losses from logging damage to succulent seedlings. During the remainder of the year, either the newly fallen seeds or the hardened first-year seedlings provide enough regeneration to allow clearcutting.

Actually, almost any method of regeneration can be, and is, used in regenerating southern pines. Other methods are used for meeting various management objectives, best achieved by partial cutting systems. Regeneration of the southern pines can be obtained by almost any method that provides for controlling competition from hardwoods, if there is enough sunlight and pine seeds or seedlings are on the ground (Hu, Lillieholm, and Burns, 1983) (Box 8.1).

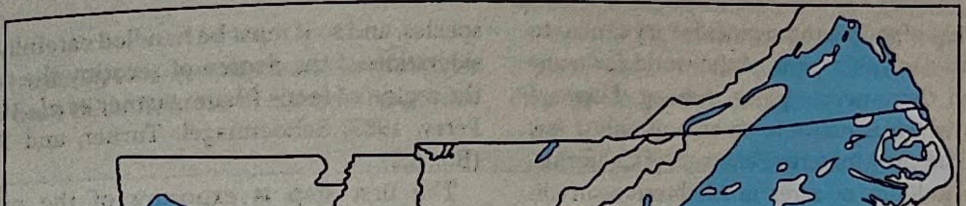
Box 8.1 Regenerating southern hard pines on the Gulf Coasts of Mississippi and Alabama using the strip clearcut regeneration method.

Introduction

In the southeast region, pine plantation forestry is now the dominant mode of regeneration (Fig. 1). Historically, many private landowners worked with natural regeneration and some still do, particularly to improve wildlife habitat (Kushla, 2009). Southern pines are long-lived shade-intolerant pioneers that grow well in open conditions. To varying degrees, most are adapted to fire. The most adapted to surviving fire as a standing tree that provide a seed source are longleaf and slash; Virginia and sand pine are more likely killed standing but the cones on their branches exhibit serotiny. Southern pines can be regenerated in a number of ways through clearcutting, seed-tree, shelterwood, or selection methods.

Regeneration

The clearcut strip method is a technique suitable for pines that have prolific seed production and relatively frequent mast years (e.g., loblolly, shortleaf, and Virginia pines) (Fig. 2). Logging should be done on the leeward side of prevailing winds in approximately 200-foot-wide strips to ensure adequate seed from the adjacent mature stand (Kushla, 2009). After logging, site preparation that includes crushing and chopping the groundstory slash and scarifying the soil surface is important. In certain circumstances, slash may be piled and burned or broadcast burned. Spring burning often helps facilitate seed dispersal of Virginia pine slash because of its cone serotiny.



Box 8.1 Figure 1 Pine forest type distributions for the major southern pine species of the southern states. *Source:* Adapted from USDA Forest Service.

(Continued)

Box 8.1 (Continued)

Box 8.1 Figure 2 Fifteen-year-old loblolly pine (*Pinus taeda*) being harvested in a strip clearcut. Slash is being chipped and the soil surface is being scarified for seed dispersal from the adjacent stand. Source: US Forest Service.

The silviculture of the southern pines is very similar to the methods used in other parts of the world for many other two- and three-needle pines. Among these are *Pinus radiata*, which is native to an area of only a few thousand acres on the Monterey Peninsula of California, but grown on millions of acres in Mediterranean climates around the world (Lewis and Ferguson, 1993), *Pinus halepensis* of the Mediterranean, and *Pinus sylvestris*, the most important European pine.

Closed-Cone Pines: Jack, Lodgepole, and Pitch Pine

The species of pines that have serotinous cones are the one important group that is generally more satisfactorily regenerated by clearcutting than by any other method. If the cones are truly serotinous, the seed crops can be stored in the crowns of the trees for many years, and there is no necessity of reserving the standing trees. The main problems are to get the cones to open and to expose enough mineral soil. If all of the cones on standing trees remain tightly closed, it may be futile to reserve any trees strictly for a source of seed. It is not possible to duplicate the severe crown fires that originate these stands, so the effects of the fires must be simulated by other means.

Reasonably successful techniques for this purpose have been developed for jack pine in the Great Lakes Region (Smith and Brown, 1984; Benzie, 1977), and sand pine on the old raised beach deposits of coastal Florida. The lodgepole pine of the Rocky Mountains is quite variable in the closed-cone habit over the range of the species, and so it must be handled carefully with full consideration of the degree of serotiny the tree has within the region of focus (Baumgartner *et al.*, 1985; Lotan and Perry, 1983; Schoennagel, Turner, and Romme, 2003) (Box 8.2).

The first step is exposure of the mineral soil by mechanical scarification. If most of the cones are tightly closed, then the cones or cone-bearing slash must be scattered over the area in such a manner so that a sufficient number of cones lie exposed to the sun within 5 in (15 cm) of the ground. Within this zone of sluggish air movement, temperatures may increase to about 120 °F (50 °C), which is the melting point of the resin that seals the cone scales. The necessity of such high surface temperatures poses a dilemma because they cause heat injury to the seedlings, so some of the seeds must fall into small spots shaded by forest debris.

It would be ideal if the scarification could be done before clearcutting, but it is usually done afterward or by appropriate modifications of harvesting procedures. The most common technique is to disk the areas after cutting and then lop and scatter the slash. If these steps are reversed, the cones are likely to be buried unopened. Success can also be achieved if the slash is bunched with bulldozer root rakes, provided that enough cones are broken off and deposited on scarified soil. Sometimes the dense little clusters of seedlings that arise from the opening of cones on the ground pose a difficult kind of precommercial thinning problem. If slash burning is necessary, it must be limited to the part of the slash that has been bunched into concentrated areas; broadcast burning destroys too many seeds.

These species have great variations in the degree to which the closed-cone characteristic occurs. It is most pronounced where forest fires have been common in nature (Schoennagel, Turner, and Romme, 2003). If the cones do not remain closed and store seeds, it is necessary to employ some sort of alternate cutting or to clearcut in narrow strips and thus depend on seeds from current production. The assumption that these species are always serotinous has led to regeneration failures in cases where reliance was placed on stored seeds that did not exist (Wyoming Forest Study Team, 1971). If some cones open and some do not, it is often necessary to compromise between the two approaches. Variations in cutting practice, degree of scarification, and slash treatment can be employed to reduce the risk of getting excessively dense natural regeneration that is likely to stagnate.

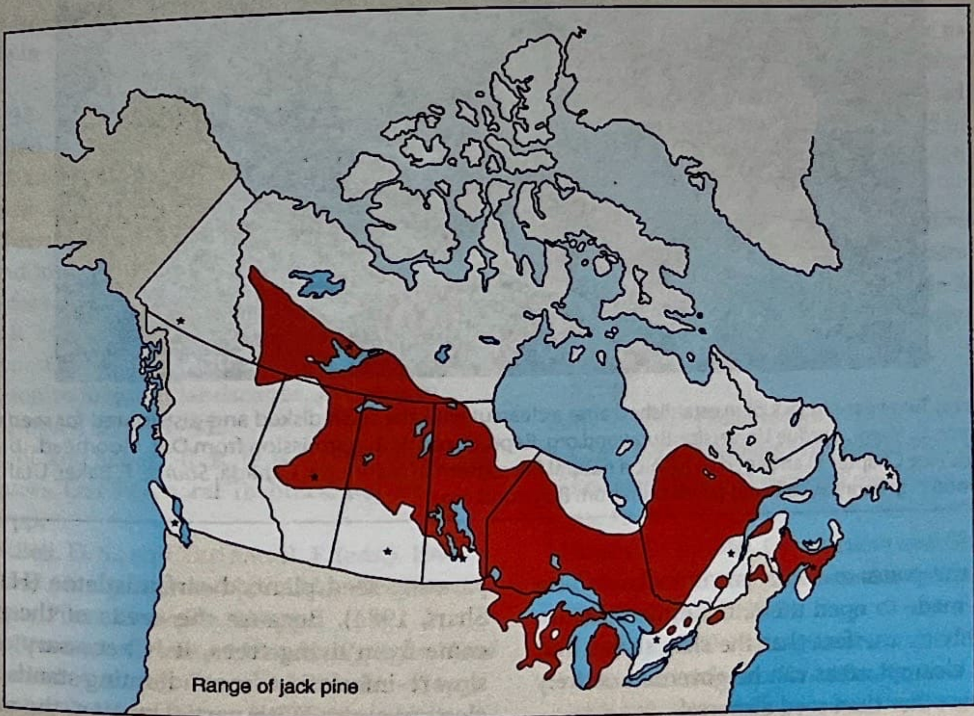
Box 8.2 Regenerating jack pine in the central provinces of Alberta, Saskatchewan, and Manitoba, Canada.

Introduction

Jack pine forests form monodominant stands across a wide range of the Interior boreal region of Canada and the US (Fig. 1). Jack pine dominates on poor, sandy soils of glacial loess origin, or granitic soils shallow to bedrock. They predominate on the Canadian Shield, the ancient land mass that is the core of proto-North America. Species associating on the wetter soils include black spruce and, on the more fertile soils, white spruce and aspen. Jack pine is maintained on the poor sites by stand-replacing fires that can occur every 50–60 years and sometimes more frequently.

Regeneration

Jack pine exhibits serotiny whereby the seed is stored in cones that open with heat, either from fire or from the sun. Seeds require open mineral soils for best germination. For this, the true clearcut method is the best method at securing natural regeneration providing the slash with the cones is evenly distributed across the site after harvest (Fig. 2). A broadcast burn can open the cones and distribute the seed or slash exposed to a few hot summer days on top of scarified soils is satisfactory. Summer is therefore the best time for harvesting so soils can be scarified (the snow and frozen ground in winter harvests protects the soil surface from scarification) and seeds germinate with the rains in the next spring. Regeneration is thick and prolific growing fast for the first 20 years or so but very susceptible to fire; by 60 years stands start to show decadence and break apart and the cycle of regeneration needs to be repeated. Jack pines are susceptible to dwarf mistletoe and a number of insects (budworm) and diseases (blights) that fire often controls.



Box 8.2 Figure 1 A range map depicting the distribution of jack pine (*Pinus banksiana*) in North America. *Source:* Adapted from US Forest Service.

(Continued)

Box 8.2 (Continued)

Box 8.2 Figure 2 (a) Two-year-old jack pine established after a clearcut with the slash disked and distributed for seed dispersal and germination. *Source:* C. Merrit, Purdue University, Bugwood.org. Reproduced with permission from D. J. Moorhead. (b) Clearcuts and seed tree methods (see Chapter 9) arranged to mimic a natural fire pattern in Manitoba, Canada. *Source:* F. Baker, Utah State University, Bugwood.org. Reproduced with permission from Bugwood.org.

owever, if all the cones are truly serotinous, definite forts must be made to open them; the difficulties are mpensated only by the fact that the size, shape, and rangement of clearcut areas can be governed entirely considerations other than seed dispersal.

An important incidental advantage of clearcutting in e management of lodgepole pine is that it provides one the surest means of eradicating infestations of the parasitic seed plant, dwarf mistletoe (Hawksworth and Sharf, 1984). Because the seeds of the pathogen must come from living trees, it is necessary only to prevent slow re-infestation from adjoining stands adjacent to the clearcut areas. With partial cutting, the mistletoe is very likely to spread from the old stand to the new, unless great care is taken to cut all the infected trees of the previous crop (Baumgartner *et al.*, 1985).

The seeds of serotinous conifers rarely exhibit dormancy, so there is little natural control over the season of germination. Therefore, the release of seed should be timed so that the seedlings will germinate at the proper season. With jack and lodgepole pine, the seeds must germinate before summer so that the seedlings will harden before the first frost. With sand pine in Florida, however, it is best to schedule scarification and slash treatment so that seedlings commence development during late fall or early winter, when rainfall is adequate and the risk of heat injury is lowest. It is indeed remarkable how much careful effort is necessary to obtain natural regeneration of these species that are adapted to reproduce themselves so easily and abundantly after catastrophic fires.

Although most hardwoods naturally grow in mixed stands, some that are pioneers in succession can form pure stands and be regenerated by clearcutting. Among these are the birches (Densmore and Page, 1992; Safford, 1983; Marquis, 1966), red alder (Hibbs, DeBell, and Tarrant, 1994), and most eucalypts (Hillis and Brown, 1984).

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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 pre-adapted 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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