8 Silviculture and Habitat Management

Even-Aged Systems

The forest disturbances described in the last chapter continue to influence the structure and composition of forests. Shift happens. But how contemporary human societies chose to use the forest and manage them for various species has an ever-increasing influence on the structure, function, and composition of forests. Although culturally induced pressures of development, invasive species proliferation, and climate change will continue to determine whether we have forests to use for other purposes, two forest management practices currently have a significant impact on habitat for many species: silviculture and fire management (both fire protection and prescribed burning). *Silviculture* is the art and practice of managing forest stands to achieve specific objectives for the landowner or land manager. These objectives could include timber production, recreation, habitat for various wildlife and fish species, biodiversity conservation, aesthetics, and nontimber forest products. Indeed many nonindustrial forest landowners in the United States own and manage land for reasons other than timber production. But it is the economic value of the forest that allows many landowners to manage their forests to achieve other objectives. Consequently, managing forest lands for habitat requires a basic understanding of silvicultural principles to be effective in achieving habitat goals. Similarly, foresters charged with recruiting, maintaining, or removing various habitat elements must understand how their silvicultural prescriptions are likely to influence habitat elements.

SILVICULTURE AS A FOREST DISTURBANCE

Silvicultural activities are forest disturbances and as such have particular sizes, severities, frequencies, and patterns across a landscape. These human-caused activities interface with the suite of natural disturbances also representing various sizes, severities, and frequencies. Managers can decide the degree to which silvicultural activities emulate natural disturbances (Fenton et al. 2009) or depart from characteristics of regional natural disturbances. In either case, the disturbances caused by people are at least in part usually additive to the disturbances caused by nonhuman forces.

Forest managers can select the types and rates of disturbances that will meet specific resource objectives and, in so doing, influence successional pathways to achieve specific goals. Some habitat management issues that foresters and wildlife biologists face may result from insufficient consideration of the size, frequency, severity, and patterning of silvicultural disturbances on a landscape. A range of management decisions can be made on any given site that will result in stand conditions and plant communities that support only certain species (Figure 8.1).

Consider, for example, an Oregon Coast Range site managed with the following combination of decisions: clearcut; no retention of logs, snags, or green trees; no site preparation; rely only on natural regeneration; no vegetation management; and no precommercial thinning. The result would probably be a red alder or salmonberry plant community with few Douglas-firs or other conifers. A similar approach in the Gulf Coastal Plain would likely result in an area dominated by oaks and sweetgum but with few pines. In northern hardwoods, however, birch–beech–maple would probably dominate the site, and in spruce–fir-dominated boreal forests in which balsam fir advance regeneration occurs, the next stand would be dominated by balsam fir. Now consider the same sites managed

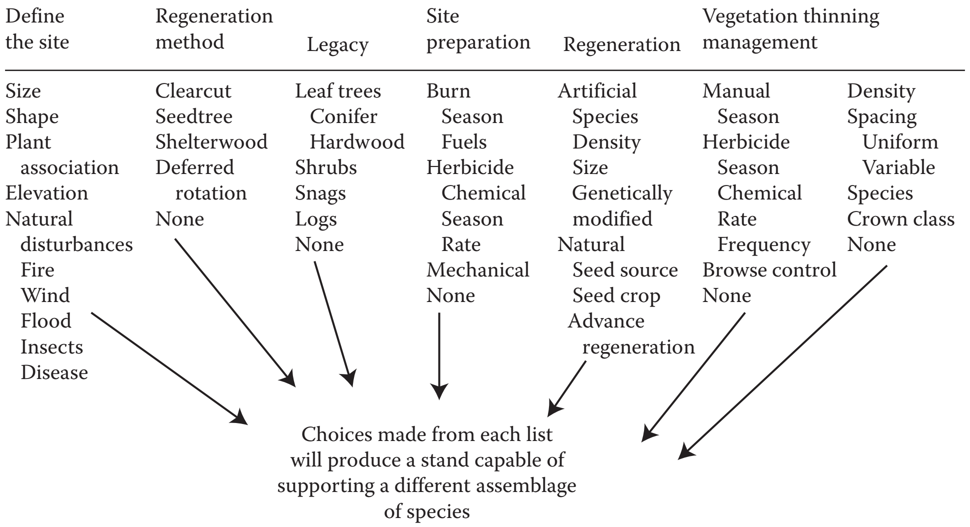

FIGURE 8.1 Decisions made by a land manager from each list will lead to development of very different forest structure and composition on a site. These choices are reflected in the availability, number, and sizes of habitat elements. (Redrafted from McComb, W.C. 2001. *Wildlife Habitat Relationships in Oregon and Washington*. OSU Press, Corvallis, OR.)

with the following decisions: clearcut, snag legacy, plant the commercially important conifer of the region, seedling release with herbicides, and thin to 750 trees/ha (300 trees/acre). The result would probably be a conifer-dominated stand condition with a grass–forb understory (sparse shrubs) during the early stages of stand development. Each condition is a habitat for a different suite of species on the same site managed in one of two ways. Many possible decisions could be made early in stand development that could produce a wide range of stand conditions (Figure 8.1).

CHARACTERISTICS OF EVEN-AGED STANDS

Once the site characteristics and stand objectives have been identified, silviculturists usually first decide whether to use an even-aged or uneven-aged silvicultural system to regenerate and maintain the stand. These two systems ensure that the desired species of new young trees will replace the trees that are cut and that they grow to achieve the landowner's objectives. Even-aged stands are those in which all or most of the trees in the stand are approximately the same age. If the trees in an even-aged stand are also all the same species, then at least during the early stages of development, most of the trees will be of similar diameter and height (Figure 8.2). The ideal distribution of tree diameters in an even-aged stand is a bell-shaped curve but often there is some departure from a normal curve. If the new stand is composed of a variety of tree species, all with somewhat different growth rates, then a different pattern emerges. Within the first few decades, the distribution of tree diameters will begin to depart from a bell-shaped curve as some trees grow rapidly in diameter and height and others grown more slowly (Figure 8.2). From the standpoint of considering vertical structure, horizontal complexity, forage resources, and other habitat elements, it is often more useful to think about the stand size-class distribution than the age distribution in mixed species stands.

Uneven-aged stands are those in which there are typically three or more cohorts or age groups represented simultaneously in the same stand. Typically, there are many more small trees than medium-sized trees and many more medium-sized trees than large trees; so the distribution of tree sizes is similar to an even-aged, mixed species stand (Figure 8.2). We will cover uneven-aged management in Chapter 9.

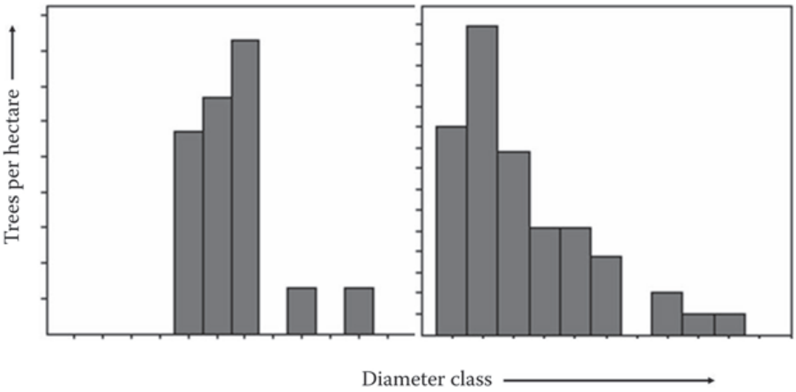

FIGURE 8.2 Distribution of live tree diameters in an even-aged stand with one species, white pine (left), and with multiple species (right) at 60 years of age as predicted using the Landscape Management System. (Adapted from McCarter, J.M. et al. 1998. *Journal of Forestry* 96(6):17–23.)

Even-aged stands typically develop through the stages of stand development described in Chapter 7: stand initiation, stem exclusion, understory reinitiation, and shifting gap phase. Depending on the goals for a stand, such as pulpwood, sawtimber, aesthetics, or habitat for certain species, this sequence of stand developmental stages may or may not be truncated. For instance, a manager growing pulpwood and providing habitat for species typically found in the stem exclusion stage may never allow the stand to enter the understory reinitiation or shifting gap-phase stages.

There are three classic methods to establish even-aged stands that will be described in more detail in the following section: clearcut, seed tree, and shelterwood. These methods can be used to initiate the stand development from stand initiation through shifting gap stages. Depending on the goals for the stand, natural disturbances can be allowed to further modify the stand structure over time if the manager decides not to salvage the dead and damaged trees in the stand.

In this chapter we also will cover two-aged stands as a modification of even-aged systems. Two-aged stands are not explicitly planned for in traditional silviculture methods, but can be quite useful when trying to retain a legacy from the previous stand or to recreate some aspects of natural disturbances such as fire and wind. Because these structures apparently occur quite commonly following natural disturbances and because they have many favorable aspects from the viewpoint of habitat element complexity, they should be standard options to be considered when planning silvicultural treatments.

CONSIDERING THE CAPABILITIES OF THE SITE

Before deciding which regeneration method to use to achieve silvicultural goals, the site must be evaluated. The size of the stand, its shape, access, slope, aspect, soils, and all of the other physical variables discussed in Chapter 5 must be taken into consideration. These factors will not only influence the type of vegetation the site can support, they also will influence the function of the vegetation in providing habitat elements on that site. For instance, an opening placed on a dry, south-facing slope with rocky ledges may be ideal for increasing habitat quality for some reptile species but may not be nearly so effective on a north-facing slope. Forest management along streams may influence the water temperature and sedimentation rates, but future stand development may be affected by beavers. So before planning any silvicultural activities, the potential for the site to support certain plant and animal species should be assessed. Ask yourself, “Can the goal that I set for the area be achieved given the physical environment in which it occurs?” If your goal could be achieved, then you should ask if it can be achieved at an appropriate cost of time and money. For instance, converting a forest to a salmonberry field in Washington or a mountain laurel field in New England may be easy and cost-effective (at least in the short run) by harvesting all trees and releasing these shrubs. On the other hand, converting these shrub fields to forests may simply not be possible without a significant initial investment of time and money.

The dominant disturbances in the area must also be considered. If your goals for the site may be compromised by a high probability of incidence of root disease, insect defoliation, browse, fire, ice, or wind, then alternative goals might be more appropriate. An excellent example is the inability to establish adequate regeneration of many commercial tree species in hardwood stands in many parts of Pennsylvania simply because of deer browsing (Marquis 1974). Attempting to grow eastern hemlock where hemlock wooly adelgid (an exotic defoliating insect) is likely to occur is another example of an impending disturbance that would compromise your ability to achieve a habitat goal. Similarly, growing dense conifer stands in wind-prone or ice-prone environments may cause much of the stand to break or be blown over (Bragg et al. 2003). So be sure that your goals for an area are consistent with the ability of the site to allow you to achieve those goals effectively and efficiently.

CHOOSING A REGENERATION METHOD

Clearcutting is probably the most commonly used silvicultural regeneration method designed to initiate an even-aged stand. This term should not be confused with a harvesting system. Harvesting systems are the means of removing the trees from the site to a landing where they can be taken to a mill, regardless of the regeneration method used. Harvesting systems include horses, skidders, cable systems, and helicopters. *Clearcutting* is a silvicultural decision designed to ensure adequate growing space for regeneration of a new stand. It is usually done to allow establishment of a plantation, though occasionally direct seeding is used to establish a new stand.

The boundary of the area to be clearcut is typically marked and then all commercial (and often noncommercial) trees are cut. If noncommercial trees and shrubs are not cut, then they are usually killed after harvest to allow rapid growth of the desired species. The size of the clearcut is usually determined by a combination of ownership boundaries, economics, and law. From simply an economic standpoint, larger clearcuts are more efficiently harvested and established than smaller ones. There are fixed costs associated with harvesting, planting, vegetation management, and thinning that are all reduced when work is in one large area rather than in many small ones. State policies and federal land management plans often dictate the upper limit of clearcut sizes that are allowed by law. Habitat concerns, especially minimum opening sizes for some species or adequate edge conditions for others will also influence clearcut size and shape.

If natural regeneration can be assured by leaving some trees after the harvest to provide a seed source to the newly created growing space, then the *seed-tree regeneration method* can be used. This approach is particularly effective for species that produce abundant seeds and produce seeds on a regular basis. Loblolly and shortleaf pines may be regenerated using this approach because they have winged seeds that disperse from the seed trees, they produce seeds regularly, and if the site is appropriate, sufficient seeds germinate and grow. Using this approach, dominant trees in the stand that have deep crowns and seem to have regular cone or seed production are identified prior to harvest and marked for retention. The number of seed trees retained depends on the dispersal capabilities of the seeds. For instance, in shortleaf pine, approximately 85% of seeds fall within 50 m (155 ft) of seed-producing trees (Burns and Honkala 1990). Seed tree spacing for this species can probably be as much as 50 m among trees, but closer if there is concern regarding seed production following harvest. Once regeneration is established, then the seed trees can be removed or retained depending on the goals and objectives for the stand. Retaining seed trees can have beneficial effects for species, such as red-cockaded woodpeckers, that use widely scattered mature trees in a savannah-like structure (Conner et al. 1991). If seed trees are retained, then there can be a reduction in growth of new seedlings for some tree species (e.g., longleaf pine; Boyer 1993).

Where newly germinated seedlings need some protection from direct sunlight, dessication, or frost, then a *shelterwood* regeneration method may be needed. A shelterwood system is designed to provide shelter or protection of the regeneration (newly established trees) by leaving a sparse canopy cover—enough to provide protection but not so much canopy cover that seedlings do not receive enough sunlight to survive and grow. This technique is most often used with tree species that are not too shade intolerant. This system is used in central hardwood oak forests (Annand and Thompson 1997), ponderosa pine (Anderson and Crompton 2002), upland mixed pine hardwood stands, mixed species jack pine stands, and northern hardwood stands, among others (Holloway and Malcolm 2006). By retaining a somewhat denser overstory to provide protection, some species that cannot survive in seed-tree stands can tolerate shelterwood stands (Taulman and Smith 2004). Establishing regeneration using the shelterwood system usually takes two to three steps. First a *preparatory harvest* is made to thin the stand and allow sunlight to strike the crowns of the dominant trees. This allows trees to increase in diameter and crown size, which increases the probability of having adequate seed production for many tree species (Dey 1995). Once seed crops seem likely or sufficient, then an *establishment or seed cut* is made to further release the trees with abundant seed production and to provide growing space for the new even-aged stand of seedlings. Finally, once the seedlings are well established and growing and can tolerate full sunlight or frost, then the overwood, or overstory, trees are removed. At least some *overwood removal* is usually necessary to allow the newly established regeneration to grow rapidly, but the level of removal is dependent on the goals for the stand.

Another type of even-aged method that has been proposed as a way of retaining some structure in these even-aged stands is the *deferred rotation* method described by Smith et al. (1986). Silviculturists also will refer to this a *clearcut with reserves*. This system retains some trees through two complete growing cycles, or rotations, in the stand and benefits certain species of animals by allowing some open-grown trees to grow large and old (Thompson and Desseker 1997, Chambers et al. 1999a). Deferment harvesting is now a commonly used technique in the central Appalachians (Thomas-Van Gundy and Schuler 2008). Rapid growth of the residual trees in combination with abundant and diverse regeneration leads to a more complex stand structure than would be seen in a traditional clearcut (Thomas-Van Gunday and Schuler 2008). Whichever system is chosen, the stand usually proceeds through site preparation, stand reestablishment, vegetation management, and stand-density management before it is ready for harvest at the end of the *rotation*, or growing cycle. Decisions at each stage influence stand structure and composition and, in turn, habitat quality for the wildlife species present at various stages of stand development (Figure 8.1).

The selection of a regeneration method will have an effect on the stand structure during the early stages of stand development (Cimon-Morin et al. 2010). Seed-tree and shelterwood systems at least initially leave vertical structure until the seed trees and overwood are removed wholly or in part. Regardless of whether natural or artificial regeneration is used to establish the new stand, the newly cleared area produces a flush of grasses, forbs, shrubs, as well as small tree, but Craig and MacDonald (2009) found that retaining more than 10%–20% of the previous stand in a boreal forest had significant effects on understory vegetation responses. Shade provided by overwood can limit production of herbs and forbs (Graham and Jain 1998). Hence, shelterwood or deferred rotation systems that, with high levels of retention, may leave an understory more similar to the preharvest stand, while retaining fewer trees may lead to an increase in understory development. The duration of this stand initiation phase, in which herbaceous plants occur and can dominate, can also be influenced by the choice of regeneration method. Because of the difficulties associated with vegetation management when residual trees are present, early vegetation control may not be possible in shelterwood stands. Consequently, the duration of the shrub condition in shelterwood stands may be longer than in clearcuts where shrubs are often controlled using herbicides. Further, the degree to which a stand is successfully regenerated can influence the duration of the stand initiation phase. Stands with high densities of tree seedlings that close crowns quickly will shade out other species, whereas low-density regeneration will allow sunlight to penetrate through crowns for a longer period of time before crown closure.

Woody and herbaceous plant species associated with these even-aged regeneration methods are often very to moderately shade intolerant, although this can be adjusted with overwood retention in shelterwood systems and with artificial regeneration. Consequently, both the structure and composition of stands can be quite variable and diverse in early stages of stand development depending on the degree to which trees are retained from the previous stand. Even-aged systems also produce stands that often create abrupt edges depending on the stature of adjacent stands. These high contrast edges are beneficial to some species (McGarigal and McComb 1995), but not to others, especially some species of amphibians (Martin and McComb 2003).

IDENTIFYING LEGACY ELEMENTS TO RETAIN

During a harvest, the land manager may decide to leave certain structural components of the previous stand on the site and into the next rotation (Franklin et al. 2007). This legacy from the previous stand is a means of adding more complexity to the new stand and allowing some of the structure, composition, and processes from the previous stand to be carried forward into the new stand. Snags are the most visible type of legacy left or created on many sites and they can significantly influence the occurrence of a number of cavity-nesting species (Bull and Partridge 1986, Schreiber and DeCalesta 1992, Chambers et al. 1997, McComb and Lindenmayer 1999). Logs, living conifers, and hardwoods (and the lichens, bryophytes, fungi, and other species associated with them) left on the site can provide structural and compositional features that create conditions in the new stand more typical of those found after natural disturbances (Pharo and Lindenmayer 2009). Recall that after most stand replacement natural disturbances, there is a considerable carryover of dead wood and also some live trees and shrubs into the new stand. Animal communities associated with stands that include these features probably would be more complex than communities in stands that lack similar components (Thompson and Desseker 1997, Chambers et al. 1999a). Diverse early successional conditions are indeed a rare feature on many landscapes where forest management has replaced natural disturbances over large areas (Swanson et al. 2010). Legacy features, however, may interfere with site preparation, vegetation management, and growth rates of the trees in the new stand, so they may only be desirable where land-management goals include resources besides timber.

Legacy trees are retained during overstory removal cuts from one rotation through most or all of the next rotation, with the new stand growing up around the reserve trees and retained habitat elements. The retained trees are not the same as seed trees. Seed trees are specifically left to provide a seed source for the next stand and then may or may not be removed. When seed trees are retained, they function in much the same way that a green-tree retention stand might (Sullivan and Sullivan 2001), but retention trees are specifically left as legacy structure in a stand although they may also provide seeds to the site. Green-tree retention and clearcut stands in Oregon seem to provide a similar habitat for many bird species when <25 trees/ha (<10/acre) are retained in retention stands (Chambers et al. 1999b). However, more species of birds typically use retention stands than clearcuts, at least in the breeding season (Vega 1993, Chambers et al. 1999b). More species were detected in uncut stands than in clearcut or retention stands during the winter (Chambers et al. 1999b). Other investigators reported similar findings in that animal responses to the retained structures were variable and dependent on the number of trees retained and their spatial pattern. The degree to which retention trees function in older stands that are nearing rotation age have not been so well studied.

SITE PREPARATION EFFECTS ON HABITAT ELEMENTS

Once the site is harvested and legacy structures have been left, then often the site must be prepared as a suitable seed bed or planting spot for the new regeneration. Site preparation may not be necessary on some sites, especially if advance regeneration is adequate. On the other hand, to ensure successful survival and growth of newly planted seedlings in plantations, site preparation can be quite intense. When managing southern pines or Douglas-fir, it is common to see a site burned and then mechanically manipulated to prepare the site for renewal. In the southern United States, mechanical site preparation may include bedding (plowing soil into raised beds where the trees are planted), chopping with a large rolling drum behind a bulldozer, or scraping the unwanted vegetation into piles or windrows with a bulldozer. This type of scarification may significantly affect the below ground structure of the stand by temporarily removing burrows and compacting soils (Todd and Andrews 2008). Burrowing species such as gopher tortoises in the southern Gulf Coast (Figure 3.9) do not seem to be directly affected by such activities, but the species that use their burrows may be (Mendonça et al. 2007). The intensity of site preparation may also affect plant communities that develop after the disturbance. Intense scarification, burning, or some herbicides may reduce shrub development in subsequent stages of stand development, at least temporarily (Newmaster et al. 2007). Alternatively, use of light fires without mechanical site preparation may proliferate the sprouting of shrubs and affect the presence or abundance of grasses and forbs in a young stand (Burton et al. 2010). The choice of site preparation influences not only the trajectory of the plant community that develops on the site, but also the level of residual "legacy" that remains after the treatment. Intense burns or mechanical scarification, for example, will usually either reduce levels of dead wood on the site or concentrate it into piles and windrows (Swift and Bell 2011). These intense treatments may be a desirable method for manipulating the habitat of some species that may influence regeneration success (such as mountain beaver), but it also may have adverse consequences for other species. In Oregon, species such as creeping voles and vagrant shrews increase after intense site preparation, but others such as Pacific and Trowbridge's shrews, ensatina salamanders, and Pacific giant salamanders decrease after site preparation (Cole et al. 1997, 1998).

Natural Regeneration and Planting Options

Land managers can determine the composition of developing stands by deciding which plant species will be re-established after site preparation. In many northern hardwood and boreal forests, advance regeneration may already be present. Clearcutting simply releases the existing regeneration (actually an overstory removal) and provides adequate light, water, or nutrients for the small trees to begin growing. In addition, the added light and heat striking the newly exposed forest floor can lead to abundant natural regeneration through germination of seed in the soil (i.e., seed bank) and through sprouting of roots and stumps. The species of plants that regenerate following a clear-cut can be quite diverse due to the availability of light, moisture, and nutrients, and the relative lack of competition. Within a short period of time, however, all growing space is occupied and there are simply too many plants competing for resources for all to grow quickly. In some instances, these plants may not be the species desired to meet habitat or timber objectives. Consequently, artificial regeneration is often used in conjunction with even-aged management approaches.

Plantations help to ensure that the appropriate species of trees are regenerated on a site to meet future objectives. Plantations can be, and often are, of a single species. From the standpoint of growing a certain product for a market, growing one species to a uniform size during one time period is economically efficient. For some animal species, the conditions provided in these uniform stands are desirable. For other species, the simple structure and composition found in monoculture plantations may not provide the habitat elements needed for survival and/or reproduction (Kerr 1999). For a variety of reasons, mixed tree species plantations are becoming more common but still represent a small fraction of the total plantation area in the world (Nichols et al. 2006). Planting one species over large areas can lead to increased risk of crop loss due to insects or disease. Swiss needle cast causes Douglas-fir trees to become defoliated but does not seriously affect western hemlock or Sitka spruce (Hansen et al. 2000). A species of invasive root rot is fatal to Port-Orford cedar but not Douglas-fir (Jules et al. 2002). Southern pine beetle may be a serious threat to loblolly or slash pines but not so seriously affect longleaf pines (Burns and Honkala 1990). So depending on the goal for the stand and the risks associated with losing certain species of trees or shrubs during stand development, mixed species stands may carry less risk and also provide certain benefits in terms of plant diversity and vertical profile diversity as the stand develops.

Plantation establishment must not only consider the species to be planted, but also the nursery stock to be used and the spacing of seedlings in the plantation. Typically, tree seedlings are transplanted to a forest after 1–2 years in a nursery. Seedlings with larger root collar diameters (stem size at the ground line) survive and grow faster than smaller seedlings (South et al. 1995, Rose and Ketchum 2003). Genetic variability and genetic resistance to insects and disease can also be considered at this period of plantation establishment. By selecting planting stock from local seed sources adapted to the local conditions, trees are more likely to survive and grow well. Genetically modified (GM) tree seedlings may also be used and it is unclear what the long-term implications of using GM plants might be to development of habitat elements in plantations. Current efforts are focused on developing herbicide- and disease-resistant strains of trees so that competing vegetation can be more effectively controlled and trees can survive common diseases. If control of competing vegetation can be made more effective, then availability of grasses, forbs, and shrubs would be reduced significantly during the earliest stages of stand reestablishment. There is also the potential to use the GM trees to influence the concentrations of secondary metabolic compounds such as phenols and tannins in seedlings and make them less palatable to vertebrate and invertebrate herbivores. The risks associated with using GM materials include the potential for gene escapement to native plants that may have unwanted and unexpected effects on their growth, survival, and value as food to herbivores (Johnson and Kirby 2001).

Seedlings grown in a nursery are often rich in nutrients to give them the best opportunity to grow and survive when they are out-planted. In addition, newly planted seedlings may be fertilized or mulched to ensure survival and growth. These treatments tend to increase their value as browse for some species because they represent a nutrient-rich source of food for some herbivores (Crouch and Radwan 1981). In many circumstances, seedlings must be protected from browse and girdling by many species of herbivores, such as deer, elk, moose, voles, gophers, mountain beavers, and American beavers (Keeton 2008). But even intensive protection treatments such as placing vexar tubes around seedlings may not be effective in all circumstances (Brandeis et al. 2002).

One factor that can have a significant effect on the production of habitat elements later in plantation development is planting density. Planting density is easily adjusted during plantation establishment. Typically, 750–1250 trees/ha are planted to establish a plantation. If trees are planted on a wide spacing, then it takes longer for the crowns of the growing trees to begin to overlap one another. When crowns begin to overlap, sunlight is no longer available to other plants or branches beneath them. Wide spacing can lead to a longer lasting grass-forb-shrub phase during the stand initiation stage of stand development. It can also lead to deep crowns and abundant limbs low on the trees, thereby increasing the number of knots in the wood when it is harvested and reducing its value unless the limbs are pruned. Variable density planting of mixed species represents a more creative way of building horizontal complexity into a stand and can lead to quite variable vertical complexity in the stand. Mixed-species planting or variable-density planting or both can provide heterogeneity in an otherwise homogenous system.

VEGETATION MANAGEMENT EFFECTS ON HABITAT ELEMENTS

Either chemical or manual vegetation control can influence the heterogeneity of developing stands. Spot control of competing vegetation could lead to a more heterogeneous stand than possible with broadcast application of a treatment. Manual control of many shrub species can lead to a proliferation of sprouts that increase amounts of available browse, but this may lead to an increase in the concentration of phenolic compounds in the leaves and twigs. Perhaps the most profound effect of vegetation management is the influence that such activities have on the future composition and structure of developing stands. Lack of any vegetation management in many northwestern or Gulf coastal sites may lead to stands with a large component of shrubs or hardwoods that will benefit some species of wildlife (Huff and Raley 1991), but interfere with tree growth and stand development.

Intensive vegetation management may lead to a conifer-dominated stand early in stand development with little shrub development unless stand density is manipulated as the stand develops. Hence, the balance between competition control and maintenance of nontimber plants requires careful thought and planning on the part of the silviculturist.

Prescribed burning is often used as a management tool to prepare sites for planting, prepare seedbeds, reduce competing vegetation, or reduce fuels and hence future fire risks. Fire is a natural and frequent event in many forest systems; so prescribed fire would seem to be a natural surrogate for uncontrolled wildfires. The choice of using fire, herbicides, or mechanical tools in forest management, either individually or collectively, is highly dependent on the types of habitat elements that a manager wishes to retain, remove, or develop in a stand. The effects that fire has on forest floor litter and dead wood can lead to adverse effects on forest floor amphibians and mammals (Randall-Parker and Miller 2002, Schurbon and Fauth 2003). On the other hand, forage quality and availability are often enhanced for herbivores following prescribed burning (e.g., Canon et al. 1987, Sparks et al. 1998). Again, as with any other forest management approach, there are species that will likely benefit from the treatment and others that will not likely benefit. The winners and losers in proposed management must be carefully considered prior to initiating a prescription, or plan, for a stand.

Herbicides and Pesticides

Use of chemicals to control vegetation in forest management is a controversial issue in many parts of the world. Effects of chemical use can be direct (the chemical affects the animal physiologically) or indirect (the chemical affects the habitat that in turn influences animal fitness). Direct effects can be lethal or sublethal, and sublethal effects can take many forms. Sublethal affects can alter an animal's behavior, alter hormonal levels, or disrupt the function of the nervous system, among other consequences. Sublethal effects can lead to a higher likelihood of the animal being killed by a predator, a disease, or a parasite. Specific examples of direct and indirect effects are provided, but the crux of the debate is around the ethics of knowingly killing or harming animals. Application of chemicals in typical forestry operations are infrequent (Christmas tree farms and other intensive plantations are an exception). Typically, herbicide may be sprayed prior to or immediately after planting and then perhaps once or twice to release seedlings until they overtop the competing vegetation. Insecticides are rarely used except in irruptions of populations that defoliate trees or cause tree mortality.

Consider three scenarios.

Scenario 1: If a chemical application kills 100 individuals of one species, say 80% of the population occurring in the stand that was sprayed, then the impact to that population is significant but may be a miniscule percentage of the entire population of that species. Over time the remaining individuals may repopulate the stand if the habitat is adequate.

Scenario 2: A chemical is applied to a stand and no animals are killed and no sublethal effects are expected, but the habitat is changed such that no individuals of this species can be found in the stand after 3 years. Where did they go? Did they all leave? Die? Simply not reproduce?

Scenario 3: No chemicals are applied and succession is allowed to advance such that the shrubs on which the species relies are absent after 10 years and the species can no longer be found in the stand. Where did they go? Did they all leave? Die? Simply not reproduce?

Which of these three scenarios is acceptable to society? Which presents an ethical dilemma? For most people in our society, applying a chemical to a site with a risk that some of the animals may die or be adversely affected physiologically is less acceptable than changing the habitat or simply letting succession cause the species to go locally extinct. This is most likely the case because if other species can be adversely affected by exposure to a chemical then the assumption is that humans may be similarly affected. In most instances, the risk to human health trumps risks to other species.

There has been growing acceptance of integrated pest management as a means of reducing reliance on chemical solutions to pest and weed problems. Although part of the reason is risk to health of humans and other species, part if the rationale is economic. Pimentel (2005) estimated economic and environmental losses due to the application of pesticides in agriculture, home use, and forestry (which accounts for a small portion of total use) in the United States were: public health, $1 billion/year; pesticide resistance in pests, $1.5 billion; crop losses caused by pesticides, $1.1 billion; bird losses due to pesticides, $2.2 billion; and ground water contamination, $2.0 billion.

Direct Effects

Given the number of species that could be affected by chemical exposure in forests in combination with the number of chemicals that could be used to address control of plants and insect pests, the possible combinations of species × chemical is immense. Bernanke and Kohler (2009) provide an excellent overview of potential effects of a suite of environmental contaminants on birds, mammals, reptiles, amphibians, and fish. A few examples of potential effects of chemicals used in forestry practices are provided simply to raise the issue of possible direct effects, but it is important to remember that different species respond to different chemicals in different ways.

Some types of pesticides have the potential to affect developmental processes in larval amphibians or reproduction of adults, though early life stages seem to be particularly vulnerable to some chemicals (Bernanke and Kohler 2009). Although direct mortality was not detected in adult amphibians (McComb et al. 2008), larval individuals can be affected and sublethal effects have been detected. In some cases, exposing larvae to 1 or 2 ppm Roundup® (active ingredient glyphosate) for 43 days in a laboratory resulted in increased mortality, earlier metamorphosis, and smaller-sized adults (Swift and Bell 2011). Swift and Bell (2011) cautioned that these effects may not be seen under typical applications of this chemical in forest management.

Another example is an arsenic-based chemical, MSMA that was widely used in Canada to control bark-beetles, which were then eaten by woodpeckers. MSMA is no longer allowed for such use in Canada, though its use was shown to have the potential to have direct effects on woodpeckers (Morrissey and Elliott 2011). In cases such as this, the prey species for the woodpecker were also adversely affected, so even if there was no direct mortality, reduced prey availability could reduce individual and population fitness (Awkerman et al. 2011).

Indirect Effects

Management of competing vegetation can significantly affect the availability of certain plant species as food and cover. Herbicide applications that release conifers can temporarily decrease the availability of shrubs for shrub-nesting birds (Morrison and Meslow 1984, Easton and Martin 1998). For small mammals and amphibians, changes in plant species composition and cover as a result of site preparation seems to have a greater effect on animal abundance than spraying of glyphosate herbicide following plantation establishment (Cole et al. 1997, 1998).

How vegetation is controlled has different effects on different species. Santillo et al. (1989) found fewer small mammals on glyphosate herbicide-treated clearcuts for 1–3 years after spraying compared with untreated clearcuts in Maine. Insectivores seemed to be most significantly affected by herbicide spraying in this study probably because of the effect that herbicides had on the vegetation and habitat for forest floor invertebrates. Herbivores also seemed to be adversely affected until vegetation recovered from spraying (Santillo et al. 1989). Santillo et al. (1989) suggested that changes in mammal abundance seemed to be associated with herbicide-induced reductions in invertebrates and plant food and cover. Patches of untreated vegetation within herbicide-treated clearcuts may provide a source of invertebrates and plants for those species adversely affected by herbicide spraying.

Herbicide applications that release conifers can temporarily decrease the availability of browse during early stages of stand development, but they also can increase the availability of browse or herbaceous cover when applied later in stand development. Jones et al. (2009) found that a combination of spraying with imazapyr and prescribed burning opened the hardwood canopy and provided an opportunity for a more diverse herbaceous layer to develop in southern U.S. pine plantations. Similarly, Sullivan and Sullivan (2003) found that plant species diversity was not adversely affected by glyphosate spraying in young conifer plantations in British Columbia (BC). Responses of plant species to herbicides in forest ecosystems differ from responses in agro-ecosystems where glyphosate is used repeatedly to reduce non-crop vegetation (weeds) in most situations. In forests, some species of birds and small mammals decline temporarily following spraying, while other species increase in abundance. Management for a mosaic of vegetation conditions within forested landscapes should help ameliorate the short-term changes in species composition accompanying vegetation management using herbicides.

Herbicides are also an important tool for control of invasive plant species, allowing recovery of native plant communities that can have positive effects on habitat quality for some species of animals (Miller et al. 2010). In many cases, invasive species may actually increase in dominance when other types of control mechanisms are used, such as manual cutting or fire (some species sprout prolifically or find a suitable seedbed in ash). Herbicides may be the most effective and cost-efficient approach to control (Flory and Clay 2009).

PRECOMMERCIAL THINNING

Precommercial thinning involves cutting or killing trees to achieve the desired density that promotes the growth of the residual trees and the development of desired stand structure and composition. This type of treatment is done early in stand development before the trees are large enough to be sold for a profit or at least offset the cost of the thinning. This activity is a net cost to the landowner. The value of precommercial thinning is to concentrate growth on the remaining trees and allow them to grow faster. Further it increases the space between the crowns of the trees in the stand and may prolong the stand initiation (grass-forb-shrub) stage of forest development. This type of management can lead to extending the period of stand development that provides habitat for many early successional vertebrate species (Dellasala et al. 1996). Openings of less than 0.1 ha (0.25 acres) in second-growth spruce–hemlock stands in southeast Alaska provide food close to cover for Sitka black-tailed deer and allowed certain bird species to occur in otherwise unsuitable habitat (Dellasala et al. 1996). Other species respond quite differently to precommercial thinning. Indices to snowshoe hare abundance in precommercially thinned stands was about half that in unthinned stands in Maine (Homyack et al. 2007), which in turn has implications for lynx (Vashon et al. 2008).

Timing of the thinning is critical. If the thinning occurs just as crowns are closing but before early successional plants have been shaded out of the stand, then the early successional conditions will be maintained later into stand development. If the thinning is done after crowns have closed and shaded out the grasses, forbs, and shrubs, then the newly created openings in the stand will be filled by those species found in the seed bank in the soil. Some of these species may be different from those species found early in stand development. Precommercial thinning influences the structure and composition of the understory and may consequently influence the vertical and horizontal complexity in a stand. Precommercial thinning can also provide the opportunity to shift the dominant plant species in a stand. Preferential cutting of hardwoods in a mixed species stand can shift stand development more to conifers, or vice versa.

COMMERCIAL THINNING

Commercial thinning is a more common intermediate treatment used during stand management. Commercial thinning manipulates stand density by harvesting trees that can be sold and thereby provide some income to at least offset the cost of the stand management treatments. As illustrated in Figure 8.3, basal area declines abruptly as trees are removed during thinning, and then the stand regrows to recover the growing space that was lost by the trees that were removed. It also is important to realize that stands that may begin with 10,000 trees/ha (4000 trees/acre) at year 10 likely will have only 500 trees/ha (200 trees/acre) at age 100. So thinning can occur naturally (self-thinning caused by competition or fire or wind) or by humans. In most forests, however, most plants that establish after a stand-replacement disturbance die in the earliest stages of stand development through competition for resources, regardless of whether humans cut or spray them.

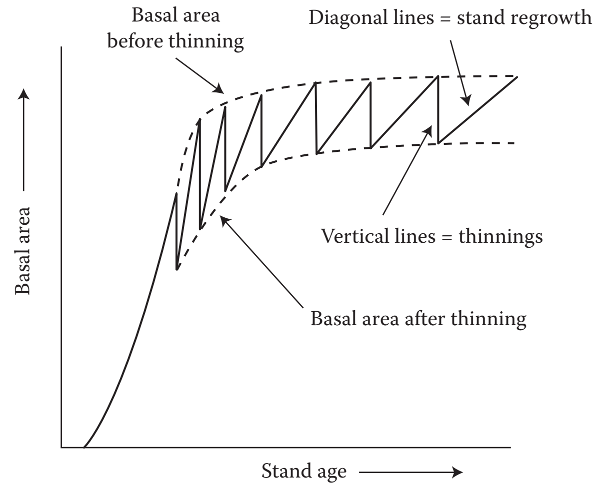

FIGURE 8.3 Stands increase in basal area over time. Thinning reduces basal area and reduces the number of trees in a stand. The residual trees grow more rapidly and recover basal area, thereby focusing increased growth on fewer, larger trees. (Smith, D.M. et al., *The Practice of Silviculture: Applied Forest Ecology*, 1997, Copyright Wiley-VCH Verlag GmbH & Co. KGaA. Reproduced with permission.)

However, the plants that do survive this period of plant competition may not always be the plants that humans want. Management action may be necessary. Management is not an ecological necessity; it is done to meet human needs and desires.

How many trees should be cut? How many should be left? One way of estimating the effects of thinning on stand growth and structure is to understand the stocking in the stand or the amount of the stand that is covered by trees in relation to the density of the stand. Stocking charts have been developed for even-aged stands in many forests in the world. Figure 8.4 provides an example of a stocking chart for an eastern white pine stand in the United States. To understand this diagram,

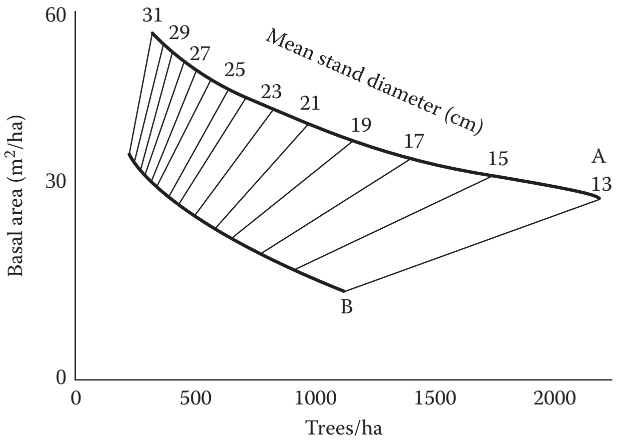

FIGURE 8.4 Eastern white pine stocking chart. Stands above the A line are considered to be overstocked (growing slowly, trees likely to die from competition). Stands below the B line are under-stocked (not all growing space is being used). Stands between the A and B line are considered to be fully stocked (growing well, all growing space is occupied). (Redrafted from Wendel, G.W. and H.C. Smith. 1990. *Silvics of North America*, Vol. 1, Conifers. USDA For. Serv. Agric. Handb. 654.)

work through an example. On the *x*-axis find stand density 200, that is, 200 trees/acre (500 trees/ha). Draw a line vertically (parallel to the *y*-axis) from this point. On the *y*-axis find 200, that is, 200 ft^2/acre (46 m^2/ha) of basal area. This is the area of the stand covered by the boles of growing trees at 1.2 m (4.5 ft) above ground. Draw a horizontal line from 200 ft^2/acre parallel to the *x*-axis. Where these two lines intersect is the stocking level for a stand with 200 trees/acre that occupy 200 ft^2 of basal area per acre. Since most trees in a single-species even-aged stand are approximately the same size, we can also estimate the average diameter of trees where these two lines cross (about 14 in [36 cm] dbh [diameter at breast height] in this case).

There are several things to notice. First, if you follow your vertical line up (increase basal area at the same number of trees per acre), tree diameters increase, up to a point. As trees get larger, eventually all growing space in the stand is occupied by trees and they begin to compete with one another. You can pack only so many trees into a hectare before some start to die. The relationship between basal area and density can also be portrayed as the relative density—that is the density of the stand at a given basal area. For example in Figure 8.5, draw a vertical line up from 1000 trees/ha on the *x*-axis. Eventually, that line will cross the upper diagonal line on this chart. This upper line indicates the maximum number of trees at a given diameter that can occur in the stand. The stand cannot add any more basal area (growing trees) at that density unless some trees in the stand die from competition. So as trees in the stand grow, some have to die and stand density will decrease. If natural disturbances or humans cutting trees do not thin the stands, then inter-tree competition leads to tree death within the stand. Trees that die from suppression mortality usually are about half the diameter of the dominant and codominant trees in the stand, which is important to keep in mind when thinking about snag formation from tree competition.

Note that neither of these charts includes anything about tree age. The rate at which trees grow to certain sizes at a given stand density and basal area is dependent on the quality of the site to grow trees. Some sites grow trees very rapidly and other sites grow the same species of tree much more slowly. Silviculturists use the term *site index* to indicate the potential of a site to grow trees in height. Why height and not diameter? Tree diameter growth is highly influenced by stand density.

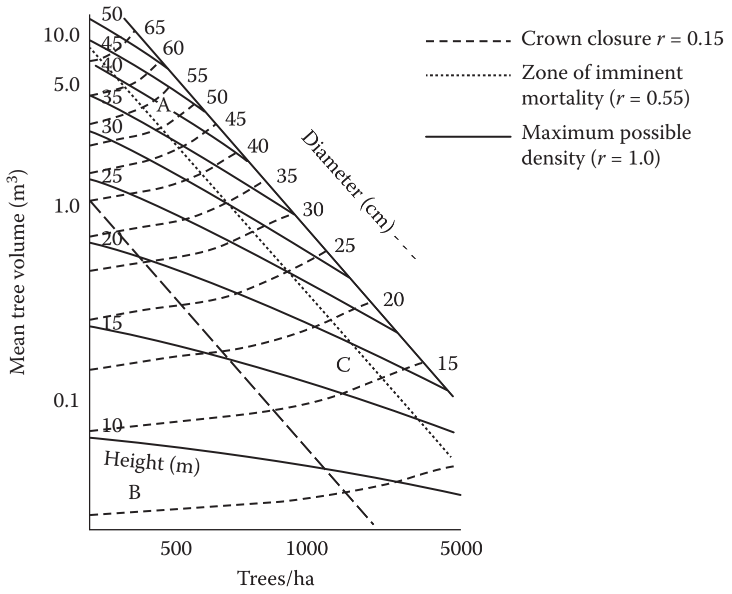

FIGURE 8.5 Stand density index diagram for coastal Douglas-fir. Stand density cannot exceed the upper diagonal line as trees compete for growing space. (Adapted and redrafted from Cameron, I.R. 1988. *An Evaluation of the Density Management Diagram for Coastal Douglas-fir*. B.C. Ministry of Forests and lands, Victoria, BC.)

A tree growing among many other trees is competing for resources and so allocates the resources it is able to capture into height growth first and diameter growth second. A tree growing in the open may not grow in height much differently than one growing in a dense stand, but the open-grown tree will have the resources that enable it to grow rapidly in diameter. Consequently, the better indicator of growth potential of a site is height because it is more independent of stand density but dependent on site quality (Figure 8.6). Foresters use the height of the dominant trees in an even-aged stand at a specified age (usually 50 years) as an index to site quality. Figure 8.6 is an example of site index curves for northern red oak in the eastern United States. Stand development, such as diameter growth, volume growth, and other features, will occur more slowly on sites with a lower site index. On high-quality sites, trees grow in diameter faster and stands increase in basal area (i.e., move through a stocking chart) more rapidly than on lower quality sites. The rate at which a stand gains volume and some habitat elements is dependent on the quality of the site.

A stocking chart (Figure 8.4) or density management diagram (Figure 8.5) can be a useful mechanism for biologists and silviculturists to work together to design stands to meet certain needs. If managers wish to produce large snags or logs, it is best to allow the trees in the stand to grow as quickly as possible until the codominant trees reach a size that is desired, and then let competition mortality kill some of those trees. In Figure 8.5, location A in the diagram would be a stand condition where 55-cm trees are competing with one another and some will have to die to allow the rest to grow. Small trees, those about half the diameter of the live trees (25–30 cm in diameter), would begin to die and add dead wood (snags and logs) to the stand. Opening the crowns by thinning also influences habitat quality for those species that find cover and food in tree crowns and in the flush of understory vegetation that might occur following thinning (location B in Figure 8.5). For instance, species that feed among tree crowns, such as Hammond's flycatchers, which perch on a branch and sally out to a space between crowns to catch flying insects, may benefit from thinning (Hagar et al. 1996). Thinning densely stocked conifer stands in landscapes dominated by younger stands enhances habitat suitability for several species of mammals and birds, but some unthinned patches and stands may be retained to provide refugia for bird species that are impacted by thinning (Location C in Figure 8.5, Hayes et al. 2003, Suzuki and Hayes 2003). Variable-density thinning can produce a wide range of tree diameters and greatly influence the production of small snags early in stand development (Carey and Wilson 2001). And some species seem to be adversely affected by thinning. Northern

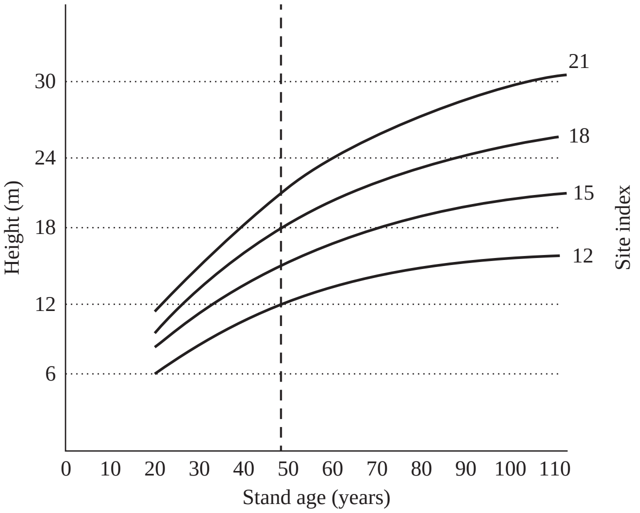

FIGURE 8.6 Site index curves for northern red oak in the Lake States. (Redrafted from Gevorkiantz, S.R. 1957. Site index curves for red oak in the Lake States. USDA For. Serv. Tech. Note 495.)

flying squirrels, an important prey species for several species of owls, seem to be negatively affected by thinning for 10 years or more after thinning has occurred (Manning et al. 2012). Thinning is conducted to accelerate development of late forest structure or restore forest functions when fire has been excluded and fuels have built up (Stephens and Alexander 2011). Consequently, when managers plan thinning treatments, the spatial arrangement of thinned and unthinned stands across a landscape over time is critical to maintaining the full suite of species that may be found in managed forests.

FERTILIZATION

Fertilization of forest stands has two dominant potential effects on habitat elements: increased diameter growth on the dominant trees and increased nutrient content in browse and forage. Added tree growth can be particularly important from a habitat complexity standpoint if some trees with added growth are retained into the next rotation. The returns in tree growth compared with the investments of fertilizer application are often most apparent on nutrient poor sites.

On nutrient-deficient sites, fertilizer applications can increase tree growth and can also increase forage production. Nutrient poor sites in the pine flatwoods of the Gulf coast are sites where fertilization seems to provide benefit to growing trees for forest products and should benefit forage for herbivores as well (Tiarks and Haywood 1996). The added nutrients that find their way into the leaves and twigs of browse plants and herbaceous forage seem to provide benefit to herbivores in a wide range of forest types. In Scandanavian conifer stands during the winter and summer following fertilization, moose strongly selected fertilized plots over unfertilized sites and hares left more fecal pellets in the fertilized plots than in untreated sites, indicating that they probably were using these fertilized patches more than unfertilized ones (Ball et al. 2000). Also in Scandanvia, fertilized stands of Norway spruce supported 38% more bird species and 21% more individuals than unfertilized stands (Edenius et al. 2011), suggesting that increased nutrient availability changed the stand structure, and perhaps increased arthropods or fruit production allowing effects to ripple through trophic levels to insectivores and fructivores as well as herbivores. Gibbens and Pieper (1962) found that fertilization increased growth and palatability of the shrubs in deer winter range in California resulting in selective thinning and browsing by herbivores. Increased browse production and use by elk has been reported following fertilizer application in Washington (Pierson et al. 1967). Selective browsing by deer on fertilized plants can reduce deer damage to fir seedlings on fertilized areas (Rieck and Jeffrey 1964 in Scotter 1980). The use of fertilizer and herbicides in combination can also benefit ungulate food resources by stimulating plant growth and by making plants more palatable (Carpenter and Williams 1972).

ROTATION LENGTH: ECOLOGICAL AND ECONOMIC TRADE-OFFS

Even-aged stands typically gain volume over time following a logistic or S-shaped curve. The average volume growth per hectare per year (mean annual increment, MAI) will peak at a point where it is economically most efficient to harvest the stand. This is called the culmination of MAI (Figure 8.7). The stand will have peaked in volume growth and delaying harvest beyond this point means that you are investing money in maintaining a stand that is no longer maximizing a profit. The point in stand development when the manager decides to harvest the stand and regenerate a new stand is the *rotation age*. The *economic rotation* age is often determined by the culmination of MAI or the point at which the stand growth begins to increase at a decreasing rate. This peak will vary depending on the site quality for the stand, the products being managed (because volumes are estimated based on product values), and the interest rate associated with income from the products derived from the stand. The culmination of MAI will occur earlier on high-quality sites (high site index), and for products requiring small tree diameters (e.g., pulp) than on poor-quality sites or for large sawtimber or veneer products. Most industrial forests will harvest stands before the culmination of MAI, and try not to carry too many stands longer than the culmination of MAI unless there is a need to provide larger products to a mill.

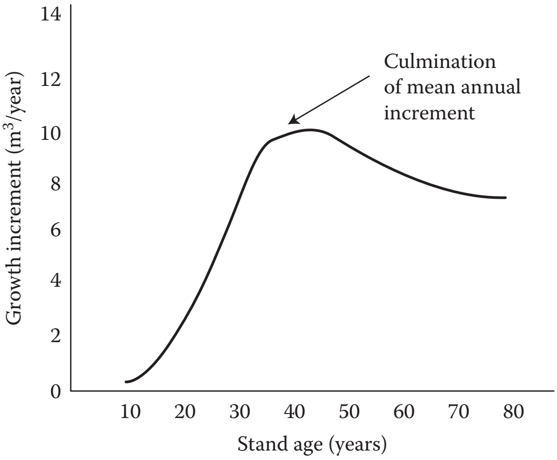

FIGURE 8.7 Change in MAI with stand age. As MAI begins to decline, stand volume is increasing at a decreasing rate and will reduce net income to the landowner over time. (Adapted and redrawn from Smith, D.M. et al., *The Practice of Silviculture: Applied Forest Ecology*, 1997, Copyright Wiley-VCH Verlag GmbH & Co. KGaA.)

The *ecological rotation* age is the average interval between stand replacement disturbances that are likely to regenerate a stand. There often is a very large difference between an economic rotation and an ecological rotation. Liu et al. (1994) modeled trade-offs between providing maximum economic return and habitat for Bachman's sparrows in southern pine forests. They found that the economic value (land expectation value) peaked at 20 years, but that rotation lengths shorter than 80 years resulted in declines in Bachman's sparrow population size (Liu et al. 1994). Species of plants and animals that typically occur in stands older than the economic rotation age will lose habitat in forests managed to maximize profit. However, the economic rotation age can be extended by thinning and by changing product goals. Further, the use of variable density plantings and thinnings, retention of legacy, and use of mixed species stands can provide many of the elements in young stands that normally might be found in older or unmanaged stands.

CASE STUDY: DOUGLAS-FIR PLANTATION

This case study provides an example of the difference in the potential structure of even-aged stands managed using approaches that consider habitat complexity. These two stands are from the mid-elevations of the western Cascades in Washington (data and projections based on Landscape Management Systems, McCarter et al. 1998). Traditional management of Douglas-fir plantations involves clearcutting followed by site preparation and vegetation management that prepares a planting site and removes as much competing vegetation as possible. In this example, 750 seedlings/ha (300 trees/acre) were planted and allowed to grow to stand age 30 as an even-aged single-species stand (Figure 8.8). At age 30, there was approximately 28 m^2/ha (120 ft^2/acre) of basal area, and 675 trees/ha with an average dbh of almost 23 cm (9 in) (Figure 8.9). At this point, a commercial thin could be implemented removing about 2 MBF (thousand board feet) per acre (5 MBF/ha) by removing those trees that would likely die through competition mortality and concentrating the remaining growth on the residual trees. The simulated thinning represents a reduction in basal area to 16 m^2/ha (70 ft^2/acre) and by stand age 50, there would be about 69 MBF/ha (28 MBF/acre) of volume to harvest in 160 trees/ha. The trees would average about 50 cm (20 in) in diameter. If sawtimber sold for $400/MBF, then the landowner would gross approximately $27,664/ha ($11,200/acre) from which harvesting, planting, and site preparation costs must be deducted.

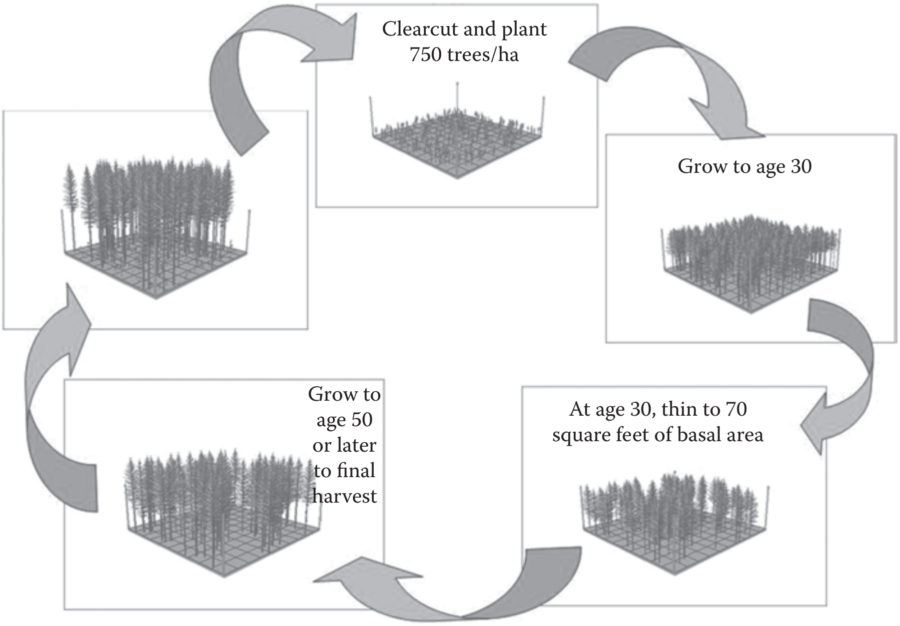

FIGURE 8.8 Example of plantation establishment and management in a Douglas-fir stand in the western Cascades of Washington. Data from Landscape Management Systems, University of Washington, Seattle. (McCarter, J.M., et al. 1998. *Journal of Forestry*, 96(6):17–23.)

Now consider a stand managed to enhance stand complexity. The stand is clearcut with 25 trees/ha (10 trees/acre) retained from the previous stand and representing five species (Douglas-fir, western hemlock, bigleaf maple, western redcedar, and black cottonwood). The site is then prepared for planting taking care to retain advance regeneration of as many species as possible, but also planting a mixture of tree seedlings representing the above species plus red alder (Figure 8.10, see Figure 8.11 for a similar approach from central Washington). At stand age 30,

FIGURE 8.9 Plantation of Douglas-fir on forest industry land in western Oregon. Note the uniformity in tree size and the lack of vertical structural complexity in this heavily stocked, even-aged stand.

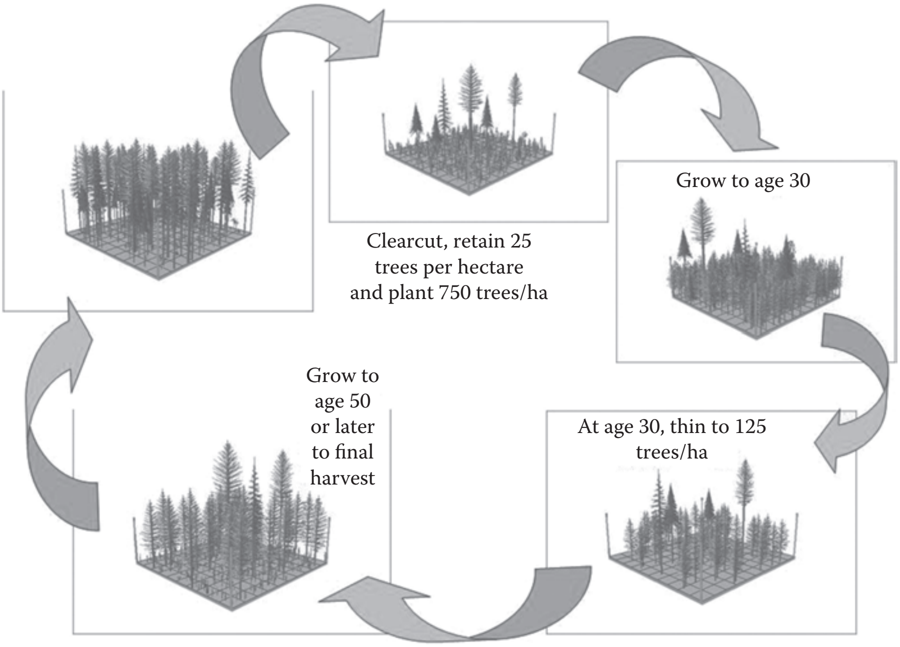

FIGURE 8.10 Example of plantation establishment and management in a Douglas-fir stand in the western Cascades of Washington that includes legacy trees, a multispecies planation, and thinning to maintain structural complexity and tree species diversity. Data from Landscape Management Systems, University of Washington, Seattle. (McCarter, J.M. et al. 1998. *Journal of Forestry*, 96(6):17–23.)

FIGURE 8.11 Seed tree regeneration method implemented in the north central Cascades of Washington. The harvest was designed to retain seed trees of ponderosa pine and western larch, with a legacy of dead trees and other species, leading to increased structural and compositional complexity early in stand development.

FIGURE 8.12 Green-tree retention stand in western Oregon 15 years after harvesting and planting. Note the increased level of structural complexity provided by regeneration, retained green trees that are still growing in size, and snags that were created following tree harvest.

there are approximately 865 trees/ha (350 trees/acre) representing seven different species, and having a total basal area of approximately 41 m^2/ha (180 ft^2/acre) and greater complexity (Figures 8.8 and 8.12). Approximately 7.5 MBF/ha (3 MBF/acre) are then removed in a commercial thin that reduces the stand density to 125 trees/ha (50 trees/acre), and the site is under-planted with a mix of five tree species to develop a second age class. At age 50, there is a broad range of tree diameters, multiple species, and approximately 84 MBF/ha (34 MBF/acre) of timber. If this mixed species sawtimber sold for $300/MBF, then the landowner would gross approximately $25,194/ha ($10,200/acre) from which harvesting, two plantings, and site preparation costs must be deducted. Hence, the bottom line profit would be less, but there still would be a profit and money to pay for developing habitat complexity.

SUMMARY

Even-aged management typically involves the use of clearcut, seed-tree, or shelterwood regeneration methods to establish a new stand consisting of one dominant tree age. The choice of the regeneration method is dependent on the characteristics of the site and the desired stand composition and structure in the future. Bird species richness and abundance are significantly higher in complex than in structurally simple plantations (Nájera and Simonetti 2009), and presumably other vertebrate taxa would be similarly affected. Stand complexity can be influenced by manipulating the number, size, and arrangement of habitat elements. Retaining legacy from the previous stand, and choices in the intensity and arrangement of site preparation, planting, and thinning activities all influence future stand complexity. The combination of choices made throughout a rotation can lead to structurally simple or complex stands at rotation age. Hartley (2002) provided some useful and simple guidelines that should be considered if a forest manager wishes to increase complexity in managed even-aged stands:

- Retain dead and living trees in the stand or in retention islands or strips where they will not interfere too badly with other stand management activities. Snag and reserve tree management (e.g., leave strips). These should include mature native trees and/or understory vegetation left unharvested or allowed to regenerate.
- Polycultures should be favored over monocultures by planting multiple crop species and/or leaving some native trees unharvested.
- Native species should generally be favored over exotics.
- Site preparation should favor methods that reflect natural disturbances and conserve dead wood.
- Thin early and frequently to retain horizontal complexity in structure and composition.
- Extend rotations as long as possible.
- Grow some crop trees through two rather than one rotation.

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