10

Natural Regeneration: The Shelterwood Method

Introduction

The goal of the **shelterwood method** is to establish new even-aged regeneration by gradually opening the canopy of a mature stand, using a series of partial cuttings. These harvests gradually reduce the canopy density of the mature stand. This method is used to promote the establishment of tree species that are mid-tolerant to very tolerant of shade, relative to their competitors in mixed stands, which are shade-intolerant pioneers that often dominate stand initiation and stem exclusion. The method provides only moderate light in the early stages of the regeneration cut. Later cuts will open the overstory to provide greater light for more rapid height growth.

The regeneration guilds of interest for the shelterwood method are the late-successional canopy dominant and the non-dominant tree species that rely upon advance regeneration (Ashton, 1992). Advance regeneration occurs when seedlings germinate and then temporarily grow in the forest understory. They fully grow and establish as a new stand after a canopy disturbance. This means that the kind of disturbance that these trees require to grow into a new stand cannot destroy the groundstory. The disturbance that promotes advance regeneration is categorized as a release type, as compared to a lethal type (see Chapter 5 on regeneration ecology). Shelterwoods emulate release disturbances, as opposed to clearcuts and seed-tree methods that emulate lethal disturbances. Shelterwoods are typically appropriate for the wet and moist forests of temperate and tropical realms (Lowe, 1977; Hannah, 1988). They can also be appropriate for particular fire-sensitive species in drier or more extreme climates, such as the Intermountain west. Species suited to shelterwoods (e.g., white pines, true firs, hemlock) are relatively more moisture loving and shade tolerant than their competitors (Helms and Standiford, 1985; Burton *et al.*, 2000). However, a common exception to this is where mixed stratified forests have long-lived shade-tolerant tree species beneath a canopy of long-lived more shade-intolerant canopy trees species. The most obvious example is the oak and hickory that grows above more shade-tolerant maple where shelterwoods must focus on securing the more shade-intolerant oaks and hickories.

The characteristic species of temperate forests that are appropriate for the shelterwood method include the maples (Godman and Tubbs, 1973; Marquis, 1979), beech (Kelty and Nyland, 1981; Agestam *et al.*, 2003), shade-tolerant birches such as the yellow and black birches (Godman and Tubbs, 1973; Marquis, 1979), red spruce, and balsam fir (Seymour, 1992; Pothier and Prevost, 2008). These species are represented in the northern hardwood (including the Allegheny plateau) and maritime regions of northeast temperate and sub-boreal North America. The mixed oak–pine–hickory forests of the midwest, south, and Atlantic regions do well with shelterwoods on drier soils and in continental temperate climates (Brose, 2010), but do not do well with more shade-tolerant competition (maples, yellow-poplar, sweetgum) on wetter sites (Loftis, 1983, 1990; Schuler and Miller, 1995; Frey *et al.*, 2007). Seed-tree systems can be more appropriate for these species on wetter sites (see Chapter 9), except for the bottomlands where the timing of masting events with more dramatic removals of the canopy are more appropriate as one-cut shelterwoods (see one-cut shelterwoods in this chapter). In the west, shelterwoods are restricted to particular sites and species. Shelterwoods are appropriate for species such as Douglas-fir and ponderosa pine on sites that have more extreme microclimates (southern aspects and droughty) (Benzie, 1977; Youngblood, 1990; Prévosto, *et al.*, 2011). Species on cooler, moister sites and northern aspects would regenerate by seed tree, such as Douglas-fir (Williamsson, 1973). The best-suited species in the west for shelterwoods on the wetter sites include the fire-sensitive and moisture-loving sugar and western white pine, western redcedar, western hemlock, and true firs (Seidel, 1983; Seidel and Cooley, 1974).

Thus, shelterwoods are focused on primarily securing species that rely upon advance regeneration. However, compared to other natural regeneration methods, shelterwoods allow the establishment of other kinds of regeneration such as pioneers and vegetative sprouts. In shelterwoods, the proportions of the different kinds of

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

regeneration, besides advance regeneration, are determined by the sprouting ability of species, the degree to which growing space that is not occupied by advance regeneration is available for colonization, and the degree of shade that may limit pioneer establishment. Because of this, shelterwoods tend to promote species compositions and structures that are diverse and complex (Fig. 10.1). It is not by chance that this regeneration method is most

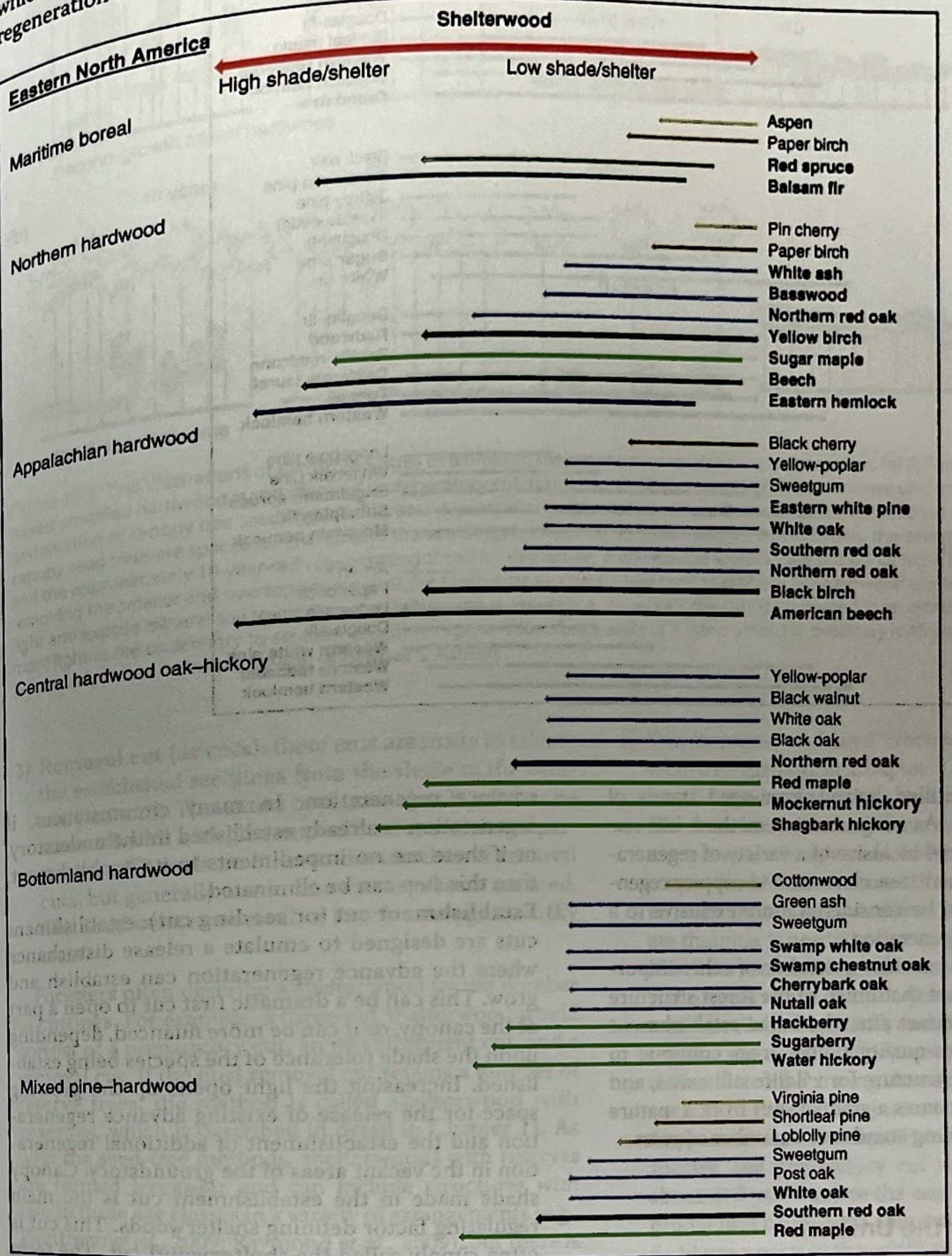


Figure 10.1 Examples of forest types and species that can be regenerated by the shelterwood method. The focus species of shelterwoods for each forest type are in bold. These species predominantly rely on advance regeneration for establishment. The darker the color green or blue, the more shade tolerant the species relative to its associates, and the more amenable to a shelterwood. Other species associates listed are mostly more shade intolerant and will regenerate (indicated by arrows) within a shelterwood, depending upon degree of canopy opening made during the establishment cut, and the nature of site preparation (if any). Shelterwoods with low shade are the most inclusive of all regeneration methods. Those with most shade are exclusive to shade-tolerant advance-regeneration species. *Source:* Mark S. Ashton.

(Continued)

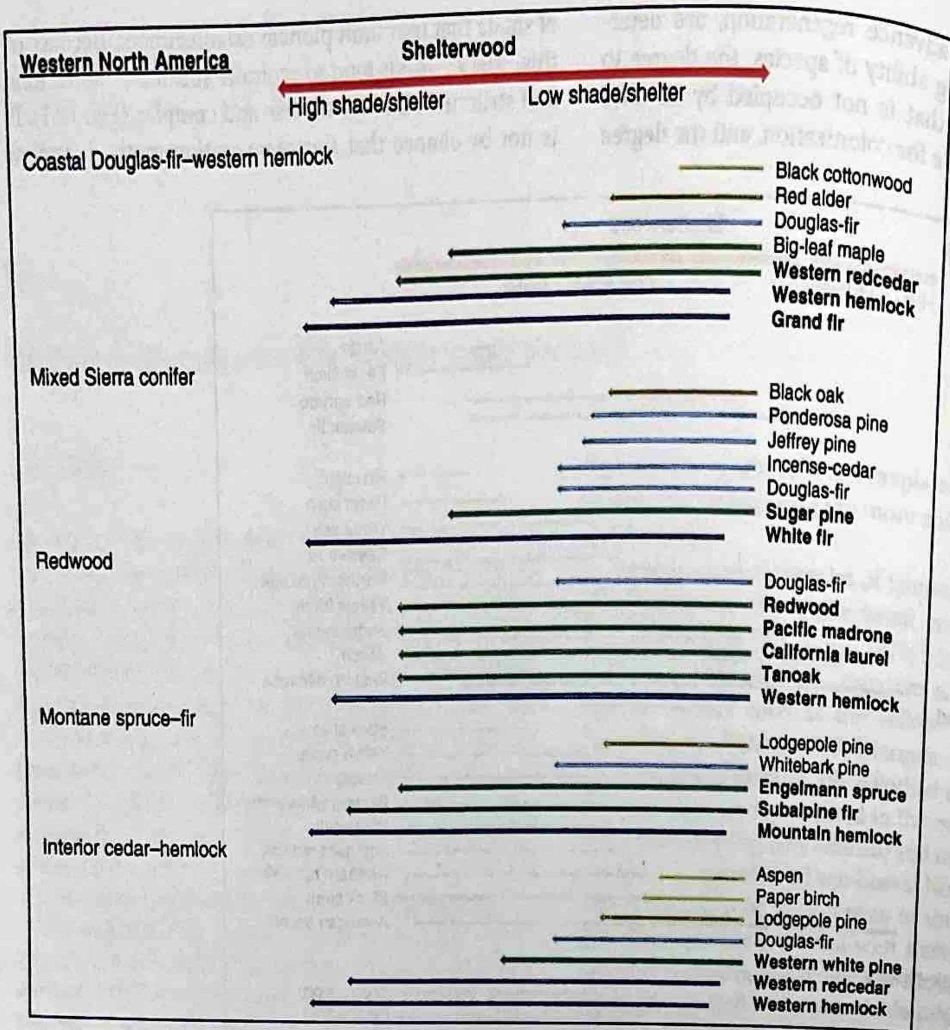


Figure 10.1 (Continued)

appropriate for stratified, mixed, even-aged stands of moist forest regions. As a regeneration method, it is one that can be considered inclusive of a variety of regeneration guilds, where seed-tree, clearcut, and coppice regeneration methods can be considered more exclusive to a particular kind of regeneration.

This method also provides a number of other important benefits. The fact that much of the forest structure of the stand is still intact after the initial establishment cut, means that high-quality timber trees continue to grow, forest habitat structure for wildlife still exists, and the visual aspect becomes a gradual shift from a mature stand to an open sapling stand over a number of years.

The Protocol for the Uniform Shelterwood

The shelterwood regeneration method generally involves two or three stages (Fig. 10.2) to complete the regeneration phase of a new stand, in the following order.

1) **Preparatory cut:** this cut is made to prepare the understory for the germination and establishment of advance regeneration. In many circumstances, if regeneration is already established in the understory, or if there are no impediments to its establishment, then this step can be eliminated.
2) **Establishment cut (or seeding cut):** establishment cuts are designed to emulate a release disturbance where the advance regeneration can establish and grow. This can be a dramatic first cut to open a part of the canopy, or it can be more nuanced, depending upon the shade tolerance of the species being established. Increasing the light opens up the growing space for the release of existing advance regeneration and the establishment of additional regeneration in the vacant areas of the groundstory. Canopy shade made in the establishment cut is the main regulating factor defining shelterwoods. This cut is often simply called the **shelterwood cut**. The term "**uniform**" comes from the fact that this cut is uniformly applied across the stand, such that the spacing between the remaining overstory trees that defines the shelterwood is relatively even. Site preparation is often needed to create forest-floor conditions for seed germination and to reduce understory vegetation.

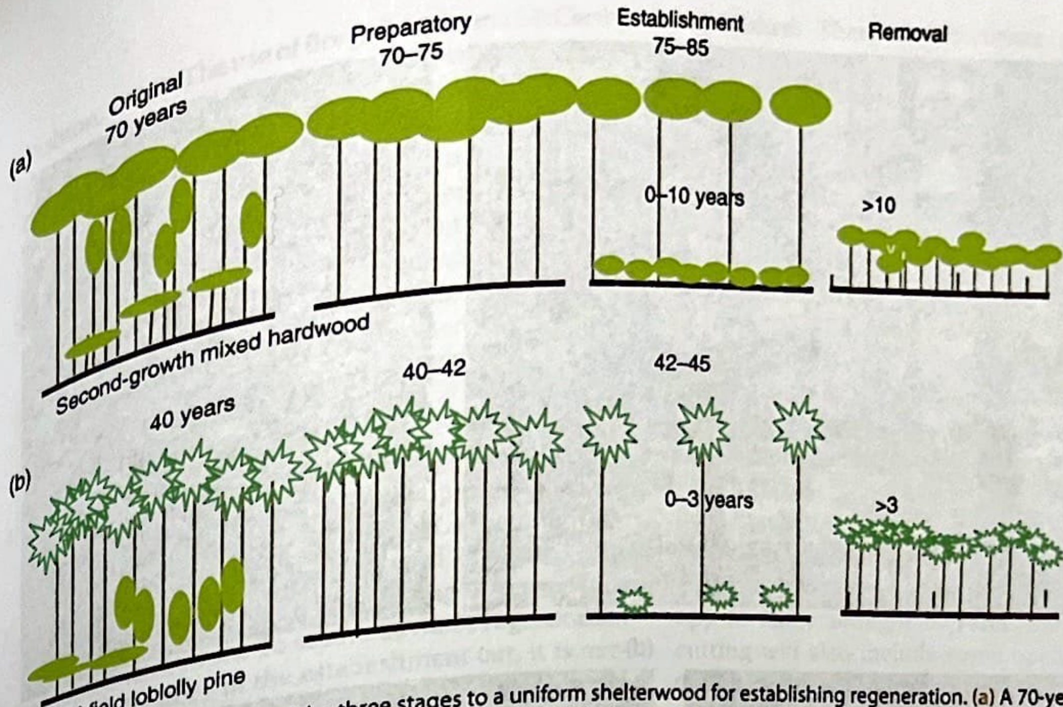


Figure 10.2 Two illustrations of the three stages to a uniform shelterwood for establishing regeneration. (a) A 70-year-old even-aged mixed-stratified hardwood stand that had a preparatory cut, taking out the lower canopy strata to increase understory light levels for germination of canopy tree seedlings. At 75 years (5 years after preparatory treatment) an establishment seed cut is performed where the canopy seed trees are spaced for shelter and the seedlings beneath can establish and grow. At 85 years, the overstory trees are removed and the approximately 10-year-old regenerating stand is released. (b) A 40-year-old loblolly pine stand that has a preparatory cut removing the smaller and overtopped trees at the same time as a prescribed burn to take out the hardwood understory. This is to increase light and expose mineral soil to secure some initial pine regeneration. At year 42, the canopy is spaced in an establishment cut to provide more light in the understory to establish the pine regeneration. A removal cut is done when the overstory is 45 years old to release the 3-year-old pine stand below. *Source:* (a, b) Mark S. Ashton.

3) **Removal cut (or cuts):** these cuts are made to release the established seedlings from the shade of the overstory canopy. The entire overstory that is left can be taken off with a single removal cut, or a series of partial cuts. There is no limit to the number of removal cuts, but generally one to three removal cuts are used. The **final cut** removes all of the remaining overstory trees.

Foresters often describe a shelterwood by the number of cuttings. For example, a three-cut shelterwood would consist of a preparatory cut, an establishment cut, and a removal cut. If the final removal cut retains a number of reserve trees, the method is called **shelterwood with reserves**, which is described in detail in Chapter 11. As with the seed-tree methods, shelterwoods with reserves are termed **irregular** and can include structures with two to three age classes in a variety of arrangements (e.g., Puettman *et al.*, 2009; Raymond *et al.*, 2009), but there is still one dominant cohort that is established and managed for the regeneration cohort.

Preparatory Cutting

There are many reasons why preparatory cutting may be necessary to ensure successful establishment of advance regeneration.

1) Windfirmness and seed crops: as described for the seed-tree method in Chapter 9, preparatory cutting may be needed for stands that are excessively dense. The trees in these stands have small crowns that cannot provide enough carbohydrates to produce large crops of seeds or to increase the size and taper of trees to make them more windfirm. In this case, a moderate thinning is needed prior to the establishment cut. If a heavy establishment cut was made in a dense stand, there would likely be poor seed crops and many tree falls (Ruel, Raymond, and Pineau, 2003). Instead, conducting a preparatory cut that might resemble uniform crown thinning throughout the stand would reduce the competition just around selected trees (see Chapter 21 for thinning). For the average stand and species, the preparatory cut should be carried out about 3–5 years before the establishment cut, if seed production is the main concern, but it would require 5–10 years prior to the establishment cut for substantial tree growth.
2) Closed-canopy conditions prevent understory development because of shade: in mature forests, where some degree of canopy break-up has occurred, the process of understory initiation (see Chapter 4) has naturally triggered establishment of advance regeneration of the late-successional canopy trees. In

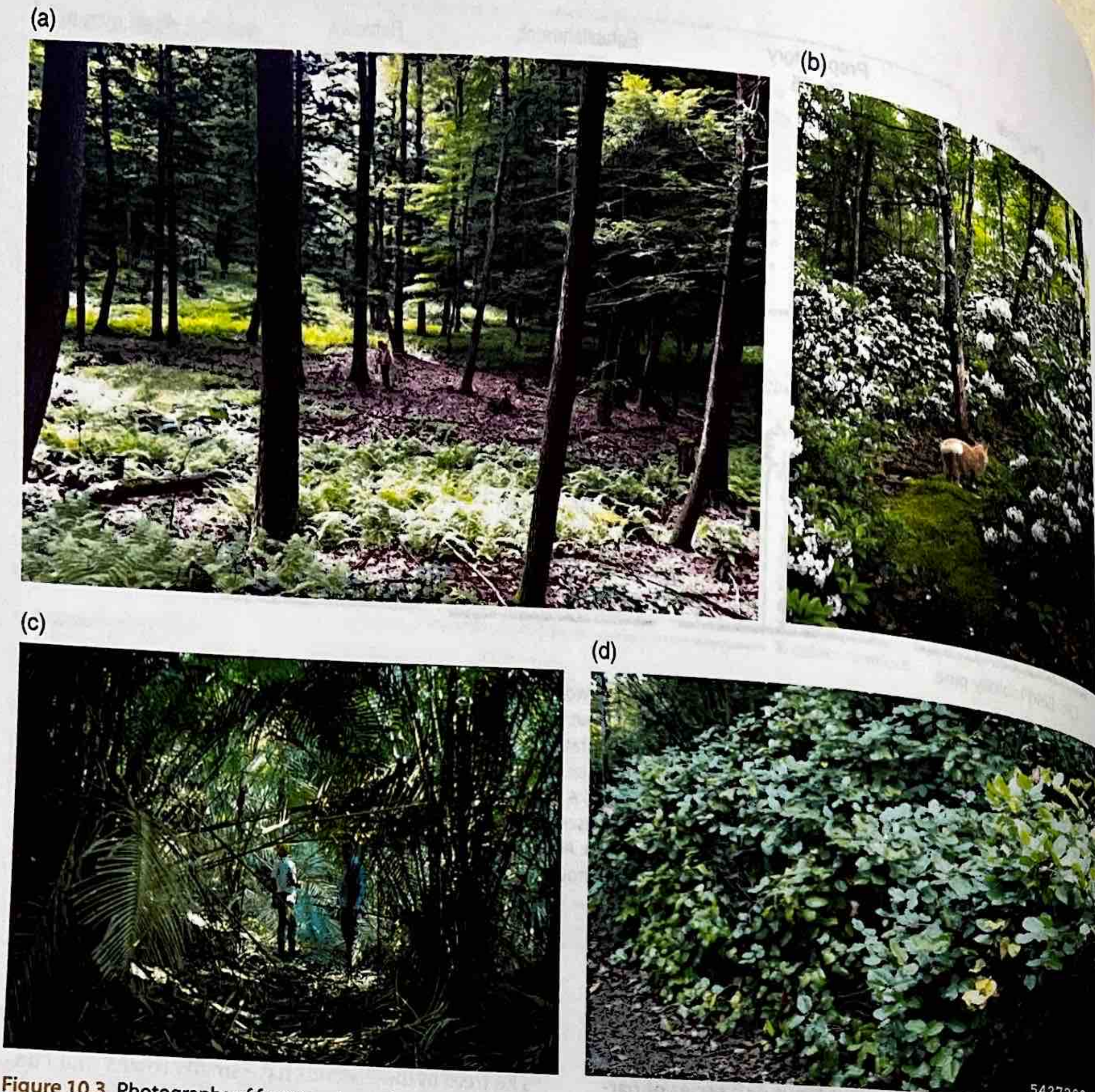


Figure 10.3 Photographs of forest understories that need to be removed in preparatory treatments to secure advance regeneration. **(a)** Hayscented fern in an even-aged, stratified, hemlock–hardwood forest of southern New England. *Source:* Mark S. Ashton. **(b)** *Kalmia* thicket (mountain laurel) in flower in a New England Forest. *Source:* Mark S. Ashton. **(c)** Palm understory in hill dipterocarp rainforest in Malaysia. *Source:* Mark S. Ashton. **(d)** Salal in a second-growth Douglas-fir forest. *Source:* C. Evans, Illinois Wildlife Action Plan. Reproduced with permission from C. Evans.

managed forests, particularly in younger second growth, this process may not have happened. Opening up the lower canopy using a preparatory cut that resembles a low thinning, increases light to the groundstory that can facilitate this process (Loftis, 1990; Man and Lieffers, 1999). In other circumstances where stands have been thinned in prior years, this process may have already happened and no preparatory cut would be needed.

3) Clonal understory plants already occupy the groundstory: many forests can develop clonal understories either naturally or from past land-use histories. In temperate moist hardwood forests, this includes various species of ferns, such as hayscented fern (Horsley and Marquis, 1983; Horsley, 1994), herbs and grasses (Harmer, Boswell, and Robertson, 2005; Donoso and Nyland, 2006), ericaceous shrubs (rhododendrons and laurels) (Clinton, Boring, and Swank, 1994; Moser, Ducey, and Ashton, 1996; Beckage *et al.*, 2000), and small trees such as *Carpinus* spp. and witch-hazel (Schuler and Miller, 1995). Similarly, this can happen in tropical forests with understory palms, bamboos, and gingers (Lowe, 1977; Ashton and Hall, 2011) (Fig. 10.3). To remove the understory and prepare the groundstory to encourage establishment of advance regeneration, preparatory cutting with a site treatment is necessary. The understory can be removed with application of herbicides (Horsley, 1994) or by prescribed burns (Brender and Cooper, 1968; Crow and Schilling, 1980; Moser, Ducey, and

Ashton, 1996). The use of fire (Albrecht and McCarthy, 2006) or cutting plus herbicide application can be useful, but it will generally have to be repeated several times (Loftis, 1990). If site treatments are applied, they generally do not involve disturbance to the soil surface like seed-tree methods, but instead serve to protect it and make it available for re-occupation by desired species that rely upon advance regeneration. The major problem in implementing preparatory cuttings and site treatments of this sort is cost. Often, no merchantable timber is taken out, so the landowner loses money in the short term.

4) Understory plants in dry forests prevent tree germination: dry forests with fully developed root systems can appear to be growing in the open with shrubs and grasses in the understory (e.g., *Ceanothus*, manzanita, salal) (Petersen, Newton, and Zedaker, 1988). However, the belowground growing space is fully occupied with roots. To secure advance regeneration in the understory in the establishment cut, it is necessary to take out some of the understory by preparatory cutting, fire, or use of herbicides (McDonald, 1976).
5) Reducing organic surface horizons: in cold, dry regions or in very wet, cool climates, forest-floor litter does not decompose rapidly, so humus accumulates and seeds cannot become established in the thick humus (e.g., spodosols). Conducting a preparatory cutting to open the canopy will provide sunlight to speed the decomposition of the forest-floor material, and to provide germinating seedlings in the establishment cutting, thus getting better access to the mineral soil nutrients and water beneath (Youngblood, 1990; Burton *et al.*, 2000; Nilsson *et al.*, 2002; Agestam *et al.*, 2003).

However, in many cases, these preparatory cuttings are not necessary because their purpose generally has been accomplished by thinning that was made in prior years, and by the natural development of the stand into understory re-initiation (see Chapter 4).

Establishment Cutting

The next step in the shelterwood method is the establishment cut, which is the true regeneration operation. The main objective is to open up enough vacant growing space to allow seedlings to become established. The ideal plan is to open the canopy enough to favor the seedlings of the desired tree species, but still provide enough overstory shade to reduce or eliminate competition from unwanted shade-intolerant species (Fig. 10.4).

Site-preparation treatments, if not done in the preparatory cutting stage, are often needed to create favorable ground conditions so that seeds can become established. These might consist of the removal of understory plants by cutting, use of fire, or herbicides. These treatments are usually applied just before or during the establishment cut. It would be ideal if the establishment cut would occur just before a good seed crop has fallen. However, the shelterwood method has an inherent safeguard because much of the seed source is still retained in the overstory trees, so it is possible to do the establishment cutting, and then, later, carry out the site preparation during a good seed year. The time period to carry out these operations varies by species and forest type.

The trees removed in the establishment cuttings of the shelterwood method come mainly from the lower crown classes. These overtopped trees and shrubs produce much of the "low shade" that reduces light to very low levels in the understory and mid-story. A low thinning (thinning from below) will remove that lower canopy to allow sunlight to reach the forest floor. The cutting will also include some openings in the upper canopy that produces light flecks and larger light patches that give short periods of direct light. With most shelterwood stands, the establishment cutting will remove trees large enough for commercial sawlogs in a harvest operation. Often, a large amount of smaller woody vegetation needs to be removed, generally with herbicide spray or stem injection, or by cutting with a brushsaw.

The appropriate density of the overstory after the establishment cut differs within wide limits, depending on the tree species, its shade tolerance, its seed-dispersal abilities, and the site conditions. It is useful to review light intensity in regard to forest canopies. To use red oak as an example, a fully mature oak stand would have 1–2% of full light at the forest floor, which would not be sufficient to produce oak seedlings (Fladeland, Ashton, and Lee, 2003). With 5% of full light, small oak seedlings can survive but not grow in height, and with 20% of full light, oak seedlings can survive, grow in height, and produce lateral shoots (Frey *et al.*, 2007). Cherrybark oak needs at least 50% full sunlight for satisfactory establishment (Gardiner and Hodges, 1998: Lockhart, Hodges, and Gardiner, 2000).

It would seem that using the percent of basal area or some other stand density measure could directly be used to determine the amount of cutting (for example, if 40% of basal area of a stand is cut, there will be 40% more light within the stand). However, this is not true, because there are multiple layers of foliage in a stand, so an establishment cut removing 40% of the stand density may give only about 10% or 20% increase in light on the forest floor. This means that an establishment cut removing 40–75% of basal area may be needed, in many cases, to produce enough light to accomplish the objective of having seedlings become well established in the

Figure 10.4 Photographs depicting the establishment cutting of a uniform shelterwood for: (a) beech–Scots pine on sandy soils in central Germany that removes about half the basal area; (b) red oak–maple–black birch forest in southern New England that removes about two-thirds of the basal area; and (c) balsam fir and red spruce in Maine that removes about one-third of the basal area. *Source:* (a–c) D. B. Kittredge, University of Massachusetts. Reproduced with permission from D. B. Kittredge.

understory, depending upon their shade tolerance (Godman and Tubs, 1973; Hannah, 1988). However, the remaining shade is essential, as it provides protection from harsh environmental conditions such as frost or extreme heat on the succulent young seedlings, and can also increase soil moisture and extend snowmelt for dry sites.

Where moisture deficiencies are likely to limit regeneration, an excessively dense overwood may cause too much root competition and interception of precipitation. If heat injury to succulent young seedlings is the primary difficulty, the establishment cutting should be regulated so as to increase the amount of diffuse light admitted from the sky as much as possible without allowing much direct sunlight to reach the forest floor.

The appropriate density of the overwood differs within wide limits, depending on the requirements of the desired species and the site factors; it may also be as important to make conditions unfavorable to problem species, as to create conditions favorable to the desirable species (Ashton, 1992; Marquis, 1966). If the species that appear are more shade tolerant than those desired, it is usually necessary to increase the severity of the establishment cutting (Martin and Hix, 1988). If, for example, the existing species to be reproduced is pine, but a more tolerant species grows rapidly after shelterwood cutting, it is probably a sign that the cutting was not heavy enough or that site preparation was inadequate (Schuler and Miller, 1995; Ray, Nyland, and Yanai, 1999). The opposite is true, if unwanted grasses or other pioneer vegetation appear. The unintended establishment of mixtures of species is usually not of concern if the desirable species outgrows the undesirable. Various indexes such as stand basal area are related to crown cover and can be used to regulate and guide the severity of establishment cuttings and thus enable transfer of experience from one case to another. Because the extraction of trees felled in the subsequent removal cuttings can cause damage to the new seedlings, it may help to take off as much of the old stand as possible in establishment cutting.

It is also useful to take advantage of all groups of advance growth that may have started naturally or as an unintentional result of past thinning. Cutting of the overstory can be much heavier in this situation, and may remove all or most of the older trees.

Removal Cuttings

Removal cuttings have the objectives of (1) gradually uncovering the new crop, and (2) taking the most merchantable trees in the overstory. There may be one or, in intensive management, several **removal cuttings**, the last of which is called the **final cutting**.

The largest and most vigorous trees usually have the greatest capacity to increase in value, and so they are the ones that are the most likely to be kept until the final cutting (Fig. 10.5). After the regeneration is established, it is desirable to watch for signs of poor growth. If the young trees develop unhealthy foliage, bend aside toward the light, or fail to maintain a satisfactory growth in height, the competition of the overwood should be eliminated or reduced. If the development of the new stand is not uniform and if there is more than one removal, it may be necessary to vary the severity of a given cutting operation in different parts of the stand area. Some patches may need full release, others may require partial release, and still others that remain unstocked may need a repetition of the establishment cutting.

It is important to distinguish between the light conditions that are suitable for the establishment of regeneration and the light needed to make them grow in height. Establishment cuttings often provide ideal shelter for new seedlings, but much heavier removal cuttings are necessary to get them to grow well. It is important that removal cuttings open stands rapidly to allow desirable species to outgrow more tolerant competitors. After they are well established, intolerant species tend to increase in height growth with each added increment of light, right up to full sunlight, whereas the tolerant species attain a modest but maximum height growth at some intermediate light intensity. The time sequence of cuttings can range from those in which old trees are left only until the new crop is established, to those in which some of the trees of the previous crop are deliberately retained as a part of the new one. Except for the need to regulate the composition and rate of development of the new crop, there is little reason why the timing cannot be fitted to any management consideration. The spatial patterns of cutting include those in which the residual trees are scattered uniformly throughout what will become one large, even-aged stand. There may also be patterns of cutting in which trees are cut or left in strips or groups; sometimes the resulting openings are gradually enlarged in sequences of cuttings (see later in this chapter for deviations from uniform arrangements of the overstory cutting).

Because of the principle of leaving the best and most vigorous trees until the end, the shelterwood systems usually provide the best way of applying the concept of financial maturity to management of the growing stock of even-aged stands. Thus, efficient use can be made of the capacity of the better trees to increase in value without sacrificing the advantages of concentration of operations associated with even-aged management. The sequence of distinctly separate operations is more visible, more systematic, and simpler to administer than is the case with uneven-aged stands.

The removal cuttings, if uniformly applied over the regeneration area, are almost certain to cause some injury to the new stand. This injury can be reduced, but not eliminated, by care in logging. The least damage is likely to result if the overwood is harvested while the seedlings are still flexible. The greatest difficulties result when it is necessary to fell trees with broad crowns into stands of saplings. The damage usually appears more serious than it really is, and it is sometimes even a benefit in disguise. Both shelterwood and seed-tree cutting often lead to the development of grossly overstocked patches of regeneration that look fine when young, but are likely to stagnate in the sapling stage. These clumps can be crudely thinned by the skidding or felling of trees across them. It is usually best to direct the inevitable logging damage toward the densest parts of the new stand or those that are entirely unstocked, and away from the sparsely stocked portions. Many species (e.g., oaks) have the capacity to re-sprout after breakage.

If the stand consists of mixed species, then the choices are more complicated. The low-thinning principle is still important but removals might also take out large trees of species with low timber quality. However, it is also important to retain smaller trees of uncommon species for ecological purposes, such as tree species diversity. Consideration is sometimes given to reserving trees that are poor for timber but good for wildlife. The use of reserves and irregular structures is described in detail in Chapter 11.

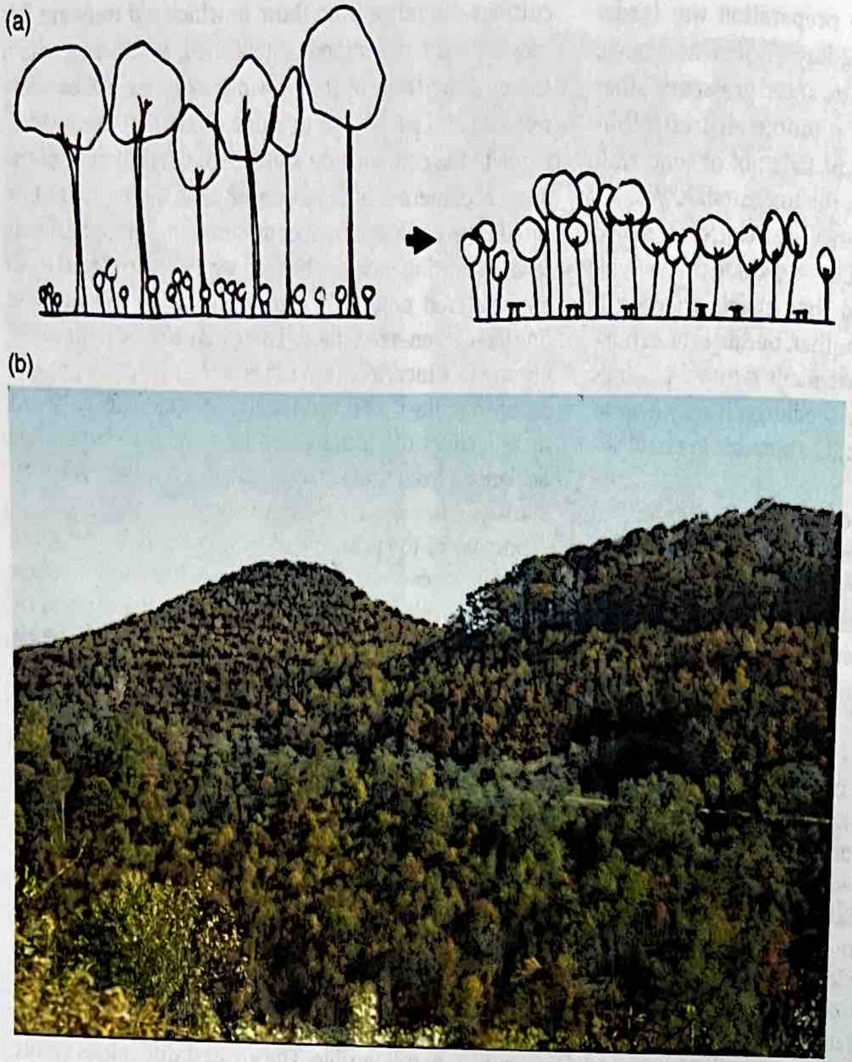


Figure 10.5 (a) A graphic depiction and (b) a photograph of a one-cut shelterwood 15 years after treatment for Appalachian mixed hardwood forest on former Westvaco land. *Source:* (a, b) Mark S. Ashton.

Protocols for Alternative Arrangements

The uniform shelterwood progresses through the three stages (preparatory, establishment, and removal cuttings) uniformly across the whole stand. However, there are other possible arrangements when implementing shelterwoods. Three are described here: (1) one-cut shelterwood; (2) strip shelterwood; and (3) group shelterwood. There are likely other ways to accomplish shelterwood operations that have yet to be formally described.

One-Cut Shelterwood

In the **one-cut shelterwood**, the practice is very simple. If the advance regeneration is already present and well established, presumably from *de facto* past thinning operations or a natural disturbance event, then there is no reason to conduct a preparatory or establishment cutting. The operation simply includes a removal cutting, usually with one entry (Fig. 10.5). They have often been erroneously defined by foresters as a "clearcut", but this does not match its proper silvicultural definition of being lethal. A one-cut shelterwood emulates a catastrophic release disturbance where the majority of the regeneration is already in place, and does not germinate afterwards or come in from the surrounding stands. Some of the best examples of applying one-cut shelterwoods are for shade-intolerant masting species (e.g., oaks) that rely upon advance growth for their representation in a new forest stand, but that compete in the understory with slower-growing shade-tolerant species. The bottomland hardwood forests of the big river systems of the southeastern US are dominated in the canopy by the red oak species (cherrybark, nuttall, willow, and water), but have thick understories of sugarberry, elm, dogwood, and sweetgum. Simple one-cut shelterwoods are a satisfactory way of releasing the oak advance regeneration above the regrowth of the shade-tolerant trees (Bowling and Kellison, 1983; Kellison and Young, 1997; Oliver, Clatterbuck, Burkhardt, 1990; Oliver, Burkhardt, and Skojac, 2005). The system works best when the canopy removal is timed to release relatively young seedlings (e.g. 1-year-old oak mast) (Oliver, Burkhardt, and Skojac, 2005).

It is very possible for early successional stands to have desirable advance growth of a later successional stage beneath them. In the Great Lakes Region, for example, red pine may follow jack pine in this manner. In New England, advance growth of maple, black birch, and oak was released from heavy timber cutting of old-field white pine at the end of the 19th century. What are seen at present in southern New England are 100-year-old second-growth, mixed-hardwood forests that originated uniformly in this manner. In another example in the Allegheny hardwood region of northwestern Pennsylvania, stands that were successively high-graded in the late 19th century built up advance regeneration beneath them. When these same stands were heavily cutover for small-dimensional materials for the wood-distillation industry in the first half of the 20th century, new single-cohort stands of mixed black cherry, sugar maple, and beech were immediately released, and grew fast and straight. Most of these cuttings were done with the pure purpose of obtaining the wood, but they were remarkably effective in the development of new uniform mixtures. Later, foresters tried to emulate this by "clearcutting" these same even-aged stands in Pennsylvania, but failed to recognize the importance of ensuring that advance regeneration was really beneath. This led to the widespread development of ferns and regeneration failure (Marquis, 1979).

Strip Shelterwood

The **strip shelterwood** is more complex. It follows the same protocols as the uniform shelterwood, but the arrangement of each of the operations consists of repeating strips that are discreetly separated (Fig. 10.6). The reason for the strip arrangement is to conduct

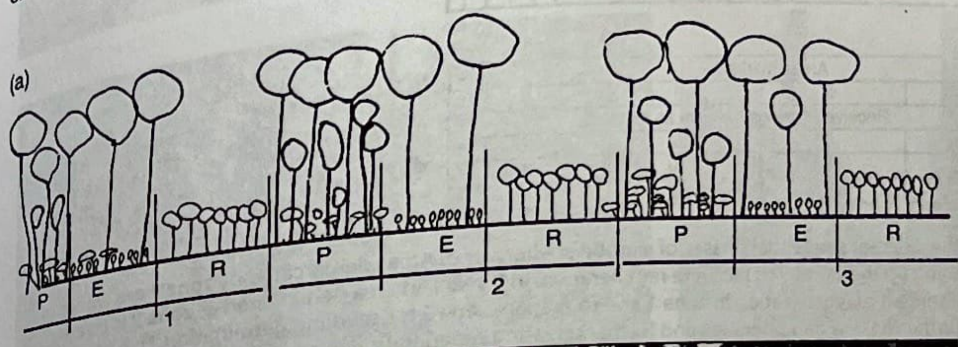
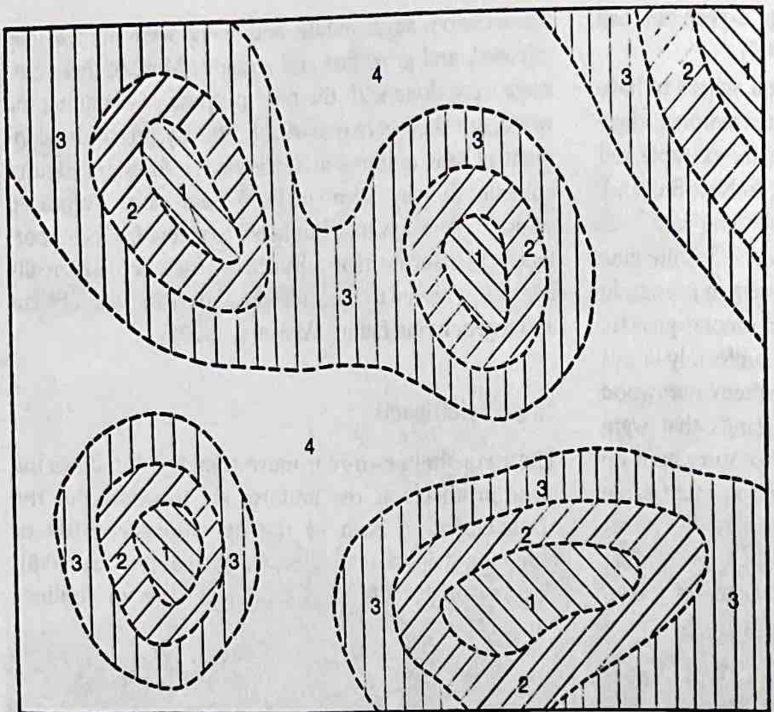


Figure 10.6 (a) A diagram illustrating the progression of strips over time using preparatory (P), establishment (E), and removal cuttings (R). What is shown is the third entry into the stand where strips in R have been preceded by entries that have had preparatory (P) and establishment cuttings, strips in E have been preceded by preparatory cuttings and strips in P only received the preparatory cutting. (b) A photograph of a strip shelterwood for Norway spruce in the Czech Republic. The man is standing on the border between establishment and removal cuttings. *Source:* (a, b) Mark S. Ashton.



Kind of cutting	Areas marked:–			
	1	2	3	4
Preparatory and seed cutting combined	Received cuttings in years as follows:–			
		0	5	10
Removal cutting		5	10	15
Final cutting	0	10	15	20

Figure 10.7 A graphic depiction of the different sequential phases of a group shelterwood. Areas demarcated by zone 1 are where the initial preparatory cuts are done opening up the canopy to facilitate regeneration. In 5 years an area demarcated as zone 2 is opened up around zone 1 to facilitate the establishment of regeneration in zone 1 and to prepare zone 2 for seedling germination. Five years later zone 3 opens up the canopy edges further, linking gap openings and further releasing regeneration in zone 2 while starting regeneration in zone 3. The final removal of the remaining canopy in zone 4 is done after enough edge light has facilitated regeneration beneath the remaining understory. *Source:* Yale School of Forestry and Environmental Studies.

shelterwoods in stands that are on slopes susceptible to erosion, or riparian areas susceptible to flooding, or exposures and aspects susceptible to windthrow. In all of these circumstances, the use of strips to counter prevailing winds, tidal or river inundations, or surface soil erosion, is an effective technique of following the shelterwood protocol in order to secure new advance regeneration at the same time as protecting the site. The strips are advanced progressively in a direction such that the timber extracted for the creation of each strip during the establishment and removal cuttings is extracted in a way that it does not cross areas of regeneration. Sometimes the strips are advanced from leeward to windward against the direction of the most dangerous storm winds.

Group Shelterwood

The third and last arrangement is the **group shelterwood** method. The mode of operation is to start in particular areas with preparatory and/or establishment cuts that create appropriately sized canopy openings suited to the shade tolerance of the regeneration being established. These openings are then sequentially expanded upon over a relatively short period, relative to the rotation (e.g., 20 years over a 100-year rotation) such that gaps finally merge and link with each other (Figs. 10.7 and 10.8). Group shelterwoods are appropriate to implement in a number of situations. An obvious example is where regeneration has already been established but in particular places, perhaps from past cutting. This provides a good opportunity to utilize these patches that can then be released and expanded upon. A second example is to use the topography and differences in soils as a guide, particularly if it is undulating with variations in drainage and fertility. The method can focus on establishing regeneration where it is easiest, and then to move back into areas that are more difficult, using the established regeneration as medium and edge for support of new smaller establishing areas.

Figure 10.8 Photographs depicting (a) preparatory and (b) establishment phases for a group shelterwood in European beech stands in the Czech Republic, and (c) preparatory and (d) establishment phases in Norway spruce–silver fir in Bavaria, Germany. *Source:* (a, b) Mark S. Ashton. (c, d) Yale School of Forestry and Environmental Studies.

Application of Shelterwood Methods

Shelterwood regeneration methods have many more variants and wider applicability than seed tree and true clearcutting. Within the framework of the shelterwood, there can be a variation in the relative degrees of shelter and exposure in both space and time. Adjustments can be made to meet the requirements of almost all species except those that are exceedingly intolerant of shade and root competition. They are the most inclusive of the even-aged methods of regeneration and can be applied to very sophisticated modes of harvesting compatible successional crops (Fig. 10.9)

Shelterwood methods simulate the effects of windstorms and similar disturbances on large trees that kill forests from the top down, and release small trees of species adapted to start as advance regeneration. The term "shelterwood" denotes one purpose succinctly: sheltering seedlings. However, like the seed-tree system, the shelterwood method is employed to distribute seed from parent trees that have poor or unpredictable dispersal agents, and to maximize the productive capacity of the growing stock by allowing the best trees to grow larger. Applications of shelterwoods are presented for the following range of forest and tree types: conifers, oak hardwoods, northern hardwoods, and tropical hardwoods.

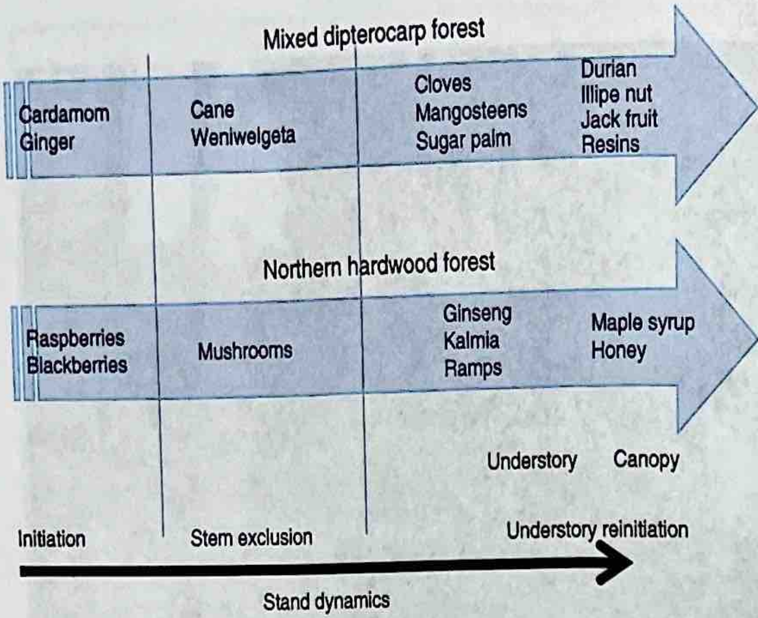


Figure 10.9 Shelterwoods can be the most inclusive natural regeneration method for complex mixed-species stands, in particular where the most shade-tolerant species rely upon advance regeneration. By including multiple species in the successional cycle, the opportunity exists of harvesting many products from trees that mature over the course of stand development ending with the timber trees. Adding all tree and non-timber species together increases the net present value of a stand by compatible stacking as compared to management for timber alone. A graphic illustration is shown for shelterwoods as sequentially successional cropping systems for non-timber forest products in a mixed dipterocarp forest from tropical Asia and a northern hardwood forest from northeastern North America. *Source:* Mark S. Ashton.

Shelterwood Methods for Conifers

The Hard Pines

The most common American use of shelterwood cutting for the regeneration of pure stands is for conifers, especially for many pine species. Though it is not widely practiced at present, it has been used successfully for loblolly and shortleaf pines, when coupled with adequate control of hardwood competition (Baker and Balmer, 1983). It is regarded as a good way of regenerating longleaf pine, which is difficult to plant and has very slow-growing seedlings (Boyer 1993). When ponderosa pine is grown using even-aged management, the regeneration is often accomplished by shelterwood cutting. In the case of the Black Hills of South Dakota, which have summer rainfall and abundant regeneration, stand management is fairly easy. In other parts of the rather large, arid range of ponderosa pine, it may be necessary to wait patiently and practice something that is between a seed-tree and a shelterwood method, in order to reduce the belowground competition for water between establishing seedlings and the groundstory shrubs. Red pine has also been successfully managed under the uniform shelterwood system, although it has been difficult to achieve prompt regeneration (Benzie, 1977; Benzie and Alm, 1977).

The Soft Pines

In the case of the moderately shade-intolerant sugar pine, eastern white pine, and western white pines, the shelterwood is advantageous for pest management and ideal for establishment of natural regeneration. For all the soft pines, the establishment cut must be severe enough to allow the pine seedlings to grow faster than their more shade-tolerant competitors, such as hemlock and fir (Box 10.1).

The main problem with growing eastern white pine is the white pine weevil (Funk, 1986). This insect often kills the terminal shoots of the trees when the tops are in the sunshine. The replacement branches are usually the laterals of the previous year, and when they turn upward, they form a crook that badly deforms the stem. One solution is to use a shelterwood overstory (older white pine or other species) to keep the young stems shaded until at least one log-length has formed (Fig. 10.10). Older white pines provide the best shade because the weevils are lured away to their sunlit crowns.

With western white pine, the introduced blister rust is the major problem. Shelterwood cutting plays a role by keeping the understory *Ribes* shrubs in-check. The *Ribes* shrub is the alternate host of the rust fungus, so the control of the *Ribes* will reduce the tree damage. The partial shade from shelterwood cutting is fine for pine seedlings, but that level of shading is too much for *Ribes* to survive and produce seeds.

Douglas-Fir, True Firs, and Spruces

Douglas-fir and many other conifers of western North America are ecologically well adapted to shelterwoods (Williamson, 1973; Seidel and Cooley, 1974; Seidel, 1983; Burton *et al*., 2000). In the past, the use of the method did not develop because of the difficulties of partial cutting, especially in ancient unstable stands and on the steep terrain that is so common. On private lands in such

Box 10.1 Regenerating the mixed conifer stands of the Sierra Nevada Mountains of California by use of shelterwood.

Introduction

There are five conifers and one hardwood that make up this mixture. This includes California black oak, ponderosa pine, Douglas-fir, incense-cedar, sugar pine, and white fir. These species dominate the middle elevations in the northern Sierras but gradually increase to high elevation on progressing south. All are killed by lethal crown fires, but white fir, the only thin-barked species of this mixture, is also susceptible to ground fires, as is sugar pine to some extent. White fir is the most shade tolerant followed by sugar pine, incense-cedar, Douglas-fir, ponderosa pine, and black oak.

Regeneration

To satisfactorily regenerate the complete mixture, it is best to focus on sugar pine. Sugar pine is intermediate in shade tolerance but has the most irregular masting events (every 3–5 years) and seeds do not disperse far from the parent tree. Black oak also has poor seed dispersal. All tree species require mineral soil for best seed germination. White fir is the most prolific seed producer. Shelterwoods are therefore designed with a preparatory cutting to take out much of the fir, followed sometimes by a surface fire to prepare the seedbed. Several years later the establishment cut can be done to space the canopy pines and fir, and to provide intermediate to low shade. Enough trees (12–20/acre; 30–50/ha) are needed to promote sugar pine dispersal, but spacing needs to allow enough light to promote the shade-intolerant ponderosa pine, incense-cedar, and Douglas-fir (Fig. 1). The number of shelterwood trees increases and their spacing decreases in relation to aspect (south versus north) and on progressing south in the Sierra.

Box 10.1 Figure 1 A shelterwood establishment cut in a mixed conifer stand leaving 20 trees/acre on the Stanislaus National Forest in the Sierra Nevada. Slash was piled and burned as a site preparation. *Source:* Mark S. Ashton.

places as western Oregon and Washington, the climate and soils are favorable for clearcutting and planting as a dependable solution. Shelterwood cutting may be used to meet goals on public lands that require more structural and compositional diversity, but partial shade is not necessary for regeneration.

Most of the region is so mountainous that elevation differences and rain-shadow effects create intricate patterns of variation in site factors to which silviculture must be adapted. One locality where shelterwood cutting seems desirable is southwestern Oregon, which has rainless summers. The problem sites include south-facing aspects, coarse-textured soils derived from granite, and low rainfall. On these sites, partial shade reduces both direct evaporation and extremes of surface temperature, enough to allow seedlings to become established from natural regeneration. In addition, the shade may reduce the establishment and spread of *Ceanothus* and manzanita shrubs, which are aggressive and can easily exclude young trees.

At high elevations, both incoming solar radiation by day and outgoing radiation by night are so great that extremes of surface temperature are very wide. They are so wide that high-elevation spruce–fir, particularly on southern aspects, are better regenerated naturally through the use of shelterwoods. However, on cool, moist northern aspects, advance regeneration can build up such that a one-cut shelterwood can work well (Ferguson and Adams, 1980).

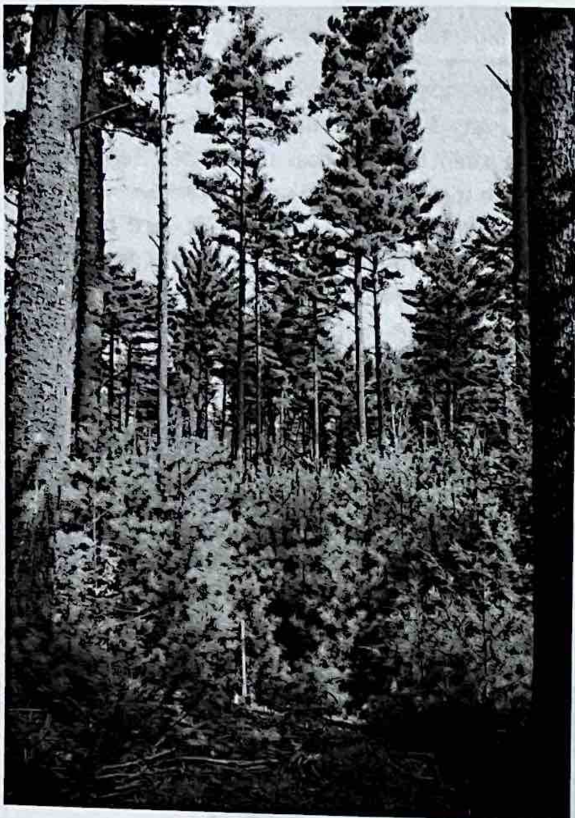


Figure 10.10 A shelterwood establishment cutting in a 74-year-old stand of eastern white pine in the Pack Forest in eastern New York. The establishment cutting was carried out 12 years prior to the photograph. The overstory is being used to reduce damage to the crowns of the seedlings from the white pine weevil. *Source:* Yale School of Forestry and Environmental Studies.

Shelterwoods are very suited to the spruce–fir forests of the northeastern maritime provinces of Canada and Maine (Seymour, 1992) as well as the forests of southwest Alaska (Greene *et al.*, 1999). In Quebec, red spruce and balsam fir regeneration grew best with establishment cuts that removed about 60% of the initial basal area (Pothier and Prevost, 2008). In Scandinavia, as could be predicted, birch (*Betula pendula* and *Betula pubescens*) is negatively associated with amount of shade, while survival and establishment of Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) were unaffected. To secure Norway spruce and Scots pine, Nilsson *et al.* (2002) recommend a canopy cover that provides partial shade (25% of initial basal area) with a soil surface that is lightly scarified to expose some of the mineral soil and encourage decomposition of organic soil.

Shelterwood Methods for the Eastern Upland Oak–Hickory Forests

Oaks are one of the most important groups of trees in eastern North American forests both in their economic and ecological value. However, assuring their regeneration through management in new forests is difficult. Most of the oak forests are a legacy of past land use. They have a history of land abuse from fire, subsistence agriculture, fuelwood, and timber cutting. Oaks flourished under these circumstances because their seed had few predators. Voles, mice, squirrels, deer, turkey, and jays were all rare because of hunting or because these animals are forest dependent and little forestland existed at that time. Oak seedlings survive surface fires, sprout vigorously, and can withstand dry open conditions (Box 10.2). Current oak stands are a main source of food for many species of wildlife, and prior to land colonization and clearance, to people as well. These forests are very different now, compared to the conditions when the oak forests arose. Now there is strong fire protection and an absence of fire on the landscape. Predators of acorns are in high numbers because forestland conditions have returned and hunting pressures are low. Fire protection has led to the rise of a more shade-tolerant, moisture-loving species assemblage (maples, black birch, yellow-poplar, sweetgum) that outcompete oak in securing space in the understory for advance regeneration. It is no wonder that trying to regenerate these forests is difficult. However, the ability to regenerate oak varies dramatically, based on site, species competition, and seeding phenology.

On drier soils and/or climates with lower continental rainfall, the more shade-tolerant moisture-loving competition is absent. Oak seedlings can establish and build up numbers that can stay in the understory for many years. All that is needed is for the forester to recognize the presence of advance regeneration on these kinds of soils. It is simplest and easiest to treat this as a one-cut shelterwood (Hannah, 1988). However, these are the very sites that should be held on to, to provide more overwood and structure for ecological or wildlife habitat purposes, because of oak's superiority at holding on to its growing space in these conditions, relative to competition from other species.

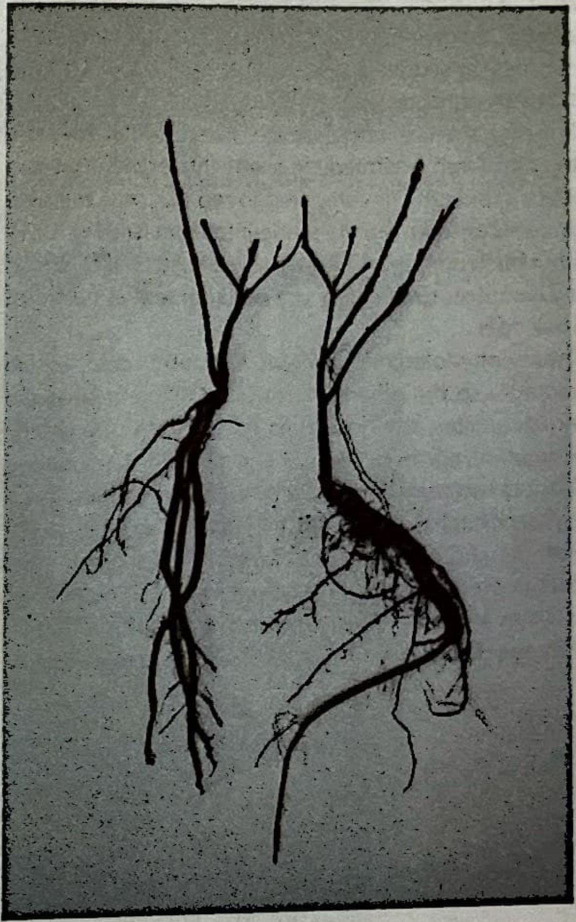
On the lower slopes and deep moist soils, or in climates with higher rainfall with more maritime influences, the oak forests that arose a century ago from past land use are much more difficult to replace. This is primarily because of competition, both during the periods of time when advance regeneration is establishing in the understory, and post-disturbance competition of what regeneration has established with other faster-growing, more shade-enduring species. A study done in southern New England (Frey *et al.*, 2007) showed that although masting events are fairly periodic, once every 3–4 years (Healey, Lewis, and Boose, 1999), actual successful seedling establishment in large cohorts within the forest understory is much less frequent (once every 10–15 years). This is complicated by the fact that on moist sites, 99% of this regeneration is dead after only a few years because of the greater canopy shade. On drier sites, high percentages have been recorded to survive longer than 20 years (Ashton, unpublished data). The establishment cut for oaks in northern

Box 10.2 The importance of seedling sprouts for regenerating oak, hickory, and other heavy-seeded nut species.

Sprouts that come from the base of small saplings and seedlings after injury (e.g., fire, browse) usually have the same anatomical and physiological origin as stump sprouts, but they also have so many attributes of seedlings that they are called **seedling sprouts**. They are defined as coming from stumps less than 1 in (2.5 cm) in diameter. This generally means that the stumps may have only sapwood and may quickly be covered over with callus tissue. Both factors greatly reduce the risk of heart-rot spreading from stump to sprout. They are considered a form of vegetative reproduction (see Chapter 12) but they are in and of themselves of seedling origin. However, they are superior to seedlings as sources of regeneration because the new shoots grow more rapidly as the result of having established root systems to nourish them. The stems tend to be straighter simply because the faster a tree grows through a certain zone of height, the less time there is for the operation of agencies that create deformities (Fig. 1).

Although almost any sprouting species can produce seedling sprouts, they are especially important with many large-seeded species such as the oaks, hickories, chestnut, and walnuts. All these species would be classified as long-lived later successional trees that are also intermediate intolerants of shade (see Chapter 5; Fig. 5.6). The seedlings of these species are seldom extremely numerous, but once established, they are very persistent and may survive for many years in the partial shade of older trees. The seedling tops continually grow up and get killed back from browsing, groundstory fires, and shade, but the carrot-like roots often survive and grow larger. When some permanent release takes place, these kinds of plants grow rapidly; they often are a chief source of regeneration for the species involved. The mechanism enables a kind of long-term storage of advance growth, especially of species that produce small numbers of large seeds. These species are therefore ideal candidates for the shelterwood method of regeneration. Studies have also documented successful oak regeneration following seed-tree and selection methods of regeneration. All of these regeneration methods would require treatments to secure their established presence before canopy removal.

While large parent-tree stump sprouts for these species can provide competitive vegetative regeneration, they are often too sparse to substantially contribute to a future stand's component, and sprouts decline in both number and vigor with the size of tree cut. The importance of advance regeneration of these species (especially oak and hickory) is well documented for a range of treatments, site indexes, and forest types. There are significant variations in the competitiveness of oak and hickory on different sites and in different forest types. For instance, xeric sites often have much more oak advance regeneration because the seedlings have greater amounts of understory light available and less competition from other species, allowing cohorts to accumulate after successive mast years. On more mesic sites, the presence of advance regeneration is tenuous as the lack of light causes high seedling mortality as compared to xeric sites where their die-back re-sprout abilities are much stronger.



Box 10.2 Figure 1 Two-year-old white oak seedling sprouts. *Source:* H. Lewis, New Hampshire State Forest Nursery. Reproduced with permission from New Hampshire State Forest Nursery.

hardwood stands is complicated because of the large number of tree species. A method for determining percent crown cover for marking trees has been made (Leak and Tubbs, 1983), using diameter at breast height (DBH)/crown cover data for the 10 main tree species.

To successfully regenerate oak on the moister soils and in wetter climates, shelterwoods are an obvious method to use. However, the regeneration often needs to be present before the establishment cutting because studies have shown it will not significantly increase afterward (Sander, 1979; Johnson, Shifley, and Rogers, 2009) (Box 10.3). Again timing is critical with best establishment often related to the release of advance regeneration that is only a year or two old.

ox 10.3 Regenerating oak on sites with shade-tolerant competitors in New England and the Appalachians

ntroduction

ree species differ in their competitive ability at different ites due to physiological and morphological characteris- ics. As a result, silvicultural treatments can have varying legrees of regeneration success depending on site quality. n the oak–hickory forests of the southern Appalachians nd southern New England, variation in competitive ability of northern red oak (*Quercus rubra*) is addressed by adjust- ng shelterwood basal area reductions across site gradi- ents and developing site-preparation treatments that favor oak compared to more shade-tolerant hardwoods.

In southern Appalachian forests, one of the primary com- petitors of northern red oak is yellow-poplar (*Liriodendron tulipifera*). Yellow-poplar competes well on high-quality mesic sites. In southern New England, black birch (*Betula lenta*) often out-competes northern red oak on mesic sites. Yellow-poplar and black birch are similar in that they are both considered intermediate shade-intolerants that can produce rapid growth compared to red oak, which is also considered an intermediate shade-intolerant (see Fig. 10.1). Neither birch nor poplar has as large a seed or allocates as many resources to seedling root development as northern red oak does.

These physiological differences confer competitive advantages to the different species on different sites. On low-quality sites, the developed root system of advance regeneration northern red oak can provide the seedling with more moisture and nutrients than either yellow-pop- lar or black birch and it holds a competitive advantage. On the other hand, on more shaded mesic sites, moisture and nutrients are more readily available, and the developed root systems of advance-regeneration oak do not confer an advantage. The silviculturalist must therefore make use of differences in shade tolerance to favor one species over another and meet regeneration goals.

Regeneration

In the USFS Bent Creek Experimental Forest in Southern Appalachians, David L. Loftis has developed basal area reduction guidelines for naturally regenerating northern red oak in shelterwood treatments. Mature fully-stocked stands are reduced to 60%, 65%, and 70% of initial basal area where oak site index is 70, 80, and 90 feet, respectively. Before cutting, herbicides should be applied in a prepara- tory treatment by stem injection to saplings and poles of shade-tolerant competitors. After the preparatory herbi- cide treatment, an establishment cutting reduces basal area from below. This can be followed up afterwards with herbicide, applied using the cut-stem method to the base of trees such as red maple and yellow-poplar to stop the sprouting. Overstory removal takes place 10 years after the treatment to allow for advance-regeneration oak to increase basal diameter and competitive ability (Loftis, 1983, 1990).

Research at Yale Myers Forest in southern New England on seedling dynamics (recruitment and survival) has informed shelterwood spacing across topographic gradients related to moisture. Spacing of canopy trees ranges from 30–45–60 ft, as a forest moves from xeric ridges, to intermediate slopes, to very mesic toe slopes. Shelterwood spacing is wider on more mesic sites to promote the relatively shade-intolerant northern red oak over the more shade-tolerant yellow-poplar and black birch.

Additionally, prescribed burns following shelterwoods have been shown to favor growth of northern red oak. In

Box 10.3 Figure 1 A typical understory of an Appalachian oak hardwood forest prior to a shelterwood. *Source:* US Forest Service.

Box 10.3 (Continued)

Box 10.3 Figure 2 Regeneration release of vigorous yellow-poplar regeneration after the establishment cut of a shelterwood. *Source:* US Forest Service.

Box 10.3 Figure 3 A prescribed burn treatment to the advance regeneration kills the yellow-poplar and promotes re-sprouting of the fire-tolerant oak beneath. *Source:* US Forest Service.

the central Appalachians of West Virginia, high- to medium-intensity spring or summer fires can reduce yellow-poplar dominance (Brose, Van Lear, and Keyer, 1999; Brose, 2010). Fire is not used to secure oak regeneration but to release it after the canopy has already been opened (Brose and Van Lear, 1998; Brose, Van Lear, and Cooper, 1999; Brose, Schuler, and Ward, 2005) (Figs. 1, 2, 3). Prescribed fires take advantage of the greater fire tolerance of oak relative to yellow-poplar or black birch, which experience higher mortality during fires and do not resprout as vigorously as northern red oak. The legacy of the single-burn treatment remained effective in releasing the oak and hickory from the competition with poplar and red maple at least 10 years later (Brose, 2010; Brose, Schuler, and Ward, 2005). Similar studies have been done in New England with mountain laurel, an evergreen shrub in the rhododendron family, but in this case the laurel sprouts back with the oak. If the burn is done after the establishment cut, the oak overtops the laurel sprouts; if the burn precedes the establishment cut, the more shade-tolerant laurel overtops the oak (Moser, Ducey, and Ashton, 1996).

Shelterwood Methods in the Northern Hardwoods

The northern hardwoods extend across North America's northeastern states, from Minnesota to Maine and from south central Canada (Ontario, Quebec) south along the Appalachians. The soils are mostly glacial and the climate is cold and moist. The dominant species include sugar maple, red maple, black cherry, beech, white ash, yellow birch, and paper birch. Eastern hemlock is the single most important conifer associated with northern hardwood. Natural disturbance regimes that renew forests range from convectional windstorms, ice storms, and occasional tornadoes, to small single-tree windthrows, droughts, and insect defoliation. Most of these forests have had a sequential series of high-grading for the best timbers during colonization, with the advancement of the frontier from east to west (1700–1850). This was followed with heavy removal cuttings for firewood, charcoal, and the wood chemical industry, during the industrial revolution (1850–1920). Across the whole region, the new forest is now mostly even-aged of 70–100 years. Unlike the oak–hickory forest, most of this forest was never cleared for agriculture and then abandoned. Its history is one of exploitation and cutting, with the subsequent release of advance regeneration. Forests that were completely cleared for pasture and agriculture went through an old-field conifer stage, after which advance regeneration became established and then eventually formed new second-growth stands.

The shelterwood is the regeneration method most suitable for the current forest structure and species composition. For the Lakes States region, Godman and Tubbs (1973) recommend two fellings for stands older than 40 years; stands that are younger and reproductively immature are difficult to regenerate by seed-origin natural regeneration. The establishment cut should remove about 40% of the initial stand basal area. To increase the yellow birch component, the proportion of basal area should be higher, the soil should be lightly scarified, and there should be some vegetative control of the beech and maple. In the Allegheny region, Marquis (1979) recommended removal of 33% of the basal area to encourage black cherry in 50–70-year-old stands, and that the overstory should be removed after 5–10 years. However, because of high deer populations, fern and grass cover can increase on poorly drained soils, creating potential interference with the seedlings; these problems need to be controlled by foliar application of herbicide (Horsley, 1994).

For the Adirondack region, the most appropriate establishment cutting to favor sugar maple and yellow birch required stand removal down to 50 ft^2/acre (11.5 m^2/ha) of residual basal area in areas that had controlled deer densities below 14 deer/$mile^2$ (36 deer/km^2), and where understory beech had had a preparatory cutting with a cut-stem application of herbicide (Kelty and Nyland, 1981). Total stem numbers peaked about 5 years after the establishment cutting and by 10 years, closed-canopy stands were rapidly self-thinning (Ray, Nyland, and Yanai, 1999). Removal cuttings should be completed by year 10. In the silvicultural guide to northern hardwoods for New England, Leak, Soloman, and DeBald (1987) suggest an establishment cutting that leaves 50–80 ft^2/acre (11.5–18 m^2/ha) with a removal cut 5–10 years afterward. This kind of treatment would provide a high proportion of shade-tolerant species in the regeneration, with sugar maple on the more fertile, higher pH soils, and beech on the poorer more acid soils. Higher deer densities promote beech and striped maple over sugar maple and white ash. Leaving lower residual basal areas of 20–40 ft^2/acre (4.5–9 m^2/ha) promotes more yellow birch. In addition, a method for determining the establishment cut for New England has been devised, based on data for tree DBH and crown cover (Leak and Tubbs, 1983). The removal cut is best done when the ground is frozen and the snow can protect the regeneration.

Shelterwood Methods in Tropical Rainforests of Southeast Asia

The mixed dipterocarp forest type dominates the southeast Asian wet evergreen rainforests. Like the oak–hardwood forests of eastern North America, these rain forests are dominated by one very species-diverse family of trees, the Dipterocarpaceae. Once widespread across the region, most of these forests in the lowlands have been selectively logged and converted to other land uses such as rubber and oil palm. There was a period of time during the heaviest exploitation (1960–2000) that dipterocarps comprised the largest volumes of timber traded on international markets in the world.

Shelterwood systems in mixed dipterocarp forests of southeast Asia have a long colonial history of development. Many dipterocarps exhibit masting, are relatively shade intolerant (red meranti type), and are site restricted, creating relatively simple mixed-species stands, with standing merchantable volumes of timber greater than 1400 ft^3/acre (100 m^3/ha). These forests are suited to uniform shelterwood treatments, where preparatory treatments are focused on establishing advance regeneration of the shade-intolerant canopy trees prior to canopy removals. Mixed dipterocarp forests can range in merchantable timber volumes from a low of 350 ft^3/acre (25 m^3/ha) on infertile or drought-prone ridge sites, or low-lying hydric swamps, to a high of over 2860 ft^3/acre (200 m^3/ha) on fertile lowlands (Nicholson, 1979; Bertault and Sist, 1997; Ashton *et al.*, 2001). This contrasts with the mahogany-rich forests of Africa and South America, where volumes of commercial timber rarely exceed 570 ft^3/acre (40 m^3/ha) when averaged across a large forest area (Verissimo *et al.*, 1995; Barreto *et al.*, 1998; Sist and Nguyen-The, 2002).

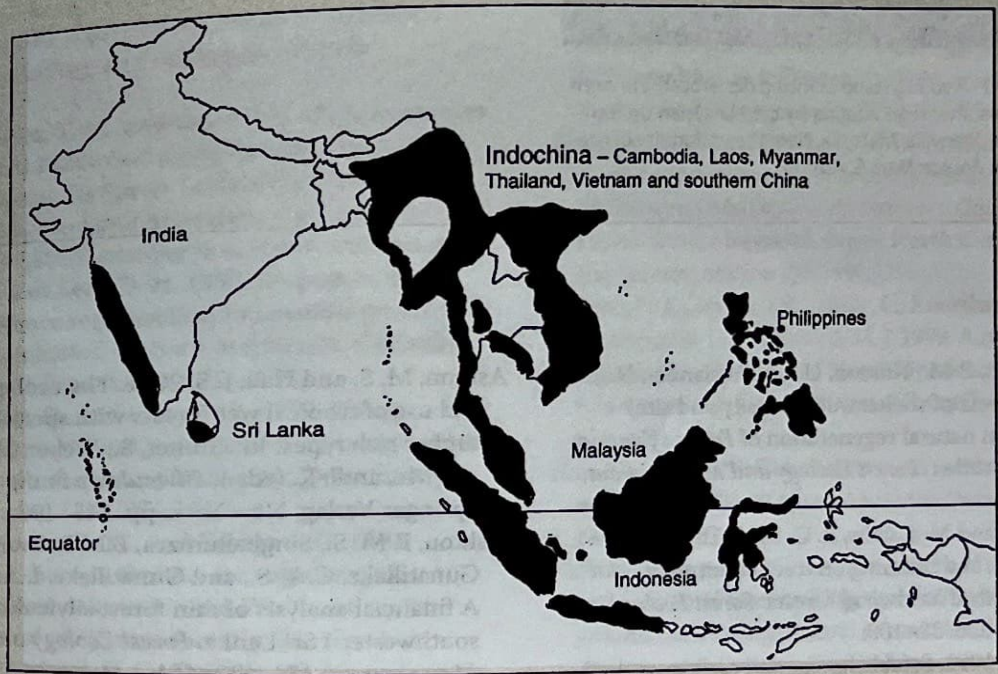
Simple systems that were developed for the Asian mixed dipterocarp forests were first successfully implemented where advance regeneration was easily secured, or where it was almost always present before any treatments were made. These conditions tended to be restricted to the lowland mixed dipterocarp forest types. The Malay Uniform System was developed as a one-cut shelterwood for forests dominated by *Shorea leprosula*, *Dryobalanops aromatica*, and other red meranti associates (Box 10.4) (Wyatt-Smith, 1963). In other lowland dipterocarp forests of South Asia, seed-tree systems for *Dipterocarpus zeylanicus* were developed (Holmes, 1957) and for forests comprising moist sal (*Shorea robusta*) in Uttar Pradesh, India one-cut shelterwoods were used (Joshi, 1980). These systems worked primarily because they were applied to forests which were dominated by one or two shade-intolerant dipterocarp species that mast and regenerate prolifically. Much of this kind of forest has now been cleared for agriculture (oil palm, rubber) and only fragments remain.

More complex shelterwood systems have been developed following uniform shelterwood protocols, but leaving various kinds and arrangements of reserves that create two or three age-class systems (multiple-aged). These will be described in further detail in Chapter 11.

Box 10.4 The Malaysian Uniform System.

Introduction

Mixed dipterocarp forest once dominated the lowlands of Malaysia (Fig. 1). This forest type comprised many timber species in the genus *Shorea* (Dipterocarpaceae). In particular, the forest type at this elevation was composed of *Shorea* species that had prolific masting, and seedlings that were present as advance regeneration in the forest understory. The most obvious timber tree that represented these traits was the light meranti *Shorea leprosula*. Research in the 1920s by researchers within the newly founded Forest Research Institute in Kepong, Malaysia, suggested that the best way to regenerate this kind of forest was a form of one-cut shelterwood. The method is summarized from years of work done at that time by Wyatt-Smith (1963) in his book *The Manual of Malayan Silviculture for Inland Forests*.



Box 10.4 Figure 1 A map depicting the original range of mixed dipterocarp forest in tropical Asia. The black depicted in the map is lowland and hill mixed dipterocarp forest. This forest type dominates climates with high rainfall areas throughout southeast Asia. *Source:* Mark S. Ashton.

(*Continued*)

Box 10.4 (Continued)

Box 10.4 Figure 2 A young stand of mixed dipterocarps in stem exclusion 25 years after regenerating by the Malaysian Uniform System at Sungei Menyala, Malaysia. Note the uniformity of the pole-sized stems. *Source:* Mark S. Ashton.

Regeneration

The Malayan Uniform System (MUS) prescribes the removal of all trees greater than 45 cm (18 in) DBH in a single cutting followed by a liberation release treatment (see Chapter 20) that girdles and poisons all remaining non-commercial trees that remained in the overstory down to 15 cm (6 in) DBH. Approximately 2–5 years after cutting and subsequent release, an inventory is carried out to determine the stocking and status of the regeneration and to decide whether further release treatments are necessary. The MUS has been applied successfully to the lowland dipterocarp forests (see Fig. 2) but is unsuitable for the hill mixed dipterocarp forests for a number of reasons. The slopes are steeper and sensitive to erosion, the stocking of the timber trees themselves is irregular, the presence of advance regeneration in the understory is both erratic and established from more irregular masting and seed-production events, and lastly the presence of the understory stemless palm (*Eugeissona triste*) shades out any potential to establish in the understory.

References

Agestam, E., Ekö, P. M., Nilsson, U., and Welander, N. T. 2003. The effects of shelterwood density and site preparation on natural regeneration of *Fagus sylvatica* in southern Sweden. *Forest Ecology and Management*, 176: 61–73.

Albrecht, M. A. and McCarthy, B. C. 2006. Effects of prescribed fire and thinning on tree recruitment patterns in central hardwood forests. *Forest Ecology and Management*, 226: 88–103.

Ashton, P. M. S. 1992. Establishment and early growth of advance regeneration of canopy trees in moist mixed-species broadleaf forest. In: Kelty, M. J., Larson B. C., and Oliver, C. D. (eds.). *The Ecology and Silviculture of Mixed-Species Forests*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 101–125.

Ashton, M. S. and Hall, J. S. 2011. The ecology, silviculture and use of tropical wet forests with special emphasis on timber rich types. In: Gunter, S., Weber, M. Stimm, B., and Mosandl, R. (eds.). *Silviculture in the Tropics*. Springer Verlag, New York. pp. 145–192.

Ashton, P. M. S., Singhakumara, B.M.P., Evans, A. E., Gunatilleke, C. V. S., and Gunatilleke, I. A. U. N. 2001. A financial analysis of rain forest silviculture in southwestern Sri Lanka. *Forest Ecology and Management*, 154: 431–444.

Baker, J. B. and Balmer, W. E. 1983. Loblolly pine. Silvicultural systems for the major forest types of the United States. *Agricultural Handbook*, 445: 148–152.

Barreto, P., Amaral, P., Vidal, E., and Uhl, C. 1998. Costs and benefits of forest management for timber

production in eastern Amazonia. *Forest Ecology and Management*, 108, 9–26.
Beckage, B., Clark, J. S., Clinton, B. D., and Haines, B. L. 2000. A long-term study of tree seedling recruitment in southern Appalachian forests: the effects of canopy gaps and shrub understories. *Canadian Journal of Forest Research*, 30: 1617–1631.
Benzie, J.W. 1977. *Manager's Handbook for Red Pine in the North Central States*. USFS General Technical Report. NC 33, 22p.
Benzie, J.W. and Alm, A. A. 1977. *Red Pine Seedling Establishment After Shelterwood Harvesting*. USFS Research Note, NC-224.
Bertault, J.-G. and Sist, P. 1997. An experimental comparison of different harvesting intensities with reduced-impact and conventional logging in East Kalimantan, Indonesia. *Forest Ecology and Management*, 94: 209–218.
Bowling, D. R. and Kellison, R.C. 1983. Bottomland hardwood stand development following clearcutting. *Southern Journal of Applied Forestry*, 7: 110–116.
Boyer, W. D. 1993. Long-term development of regeneration under longleaf pine seed tree and shelterwood stands. *Southern Journal of Applied Forestry*, 17: 10–15.
Brender, E. V. and Cooper, R. W. 1968. Prescribed burning in Georgia's Piedmont loblolly pine stands. *Journal of Forestry*, 66: 31–36.
Brose, P. H. 2010. Long-term effects of single prescribed fires on hardwood regeneration in oak shelterwood stands. *Forest Ecology and Management*, 260: 1516–1524.
Brose, P. H., Schuler, T. M., and Ward. J. S. 2005. Responses of oak and other hardwood regeneration to prescribed fire: what we know. In *Fire in Eastern Oak Forests: Delivering Science to Land Managers*, Conference Proceedings, USDA Forest Service, Newtown Square, PA.
Brose, P. H. and Van Lear, D. H. 1998. Responses of hardwood advance regeneration to seasonal prescribed fires in oak-dominated shelterwood stands. *Canadian Journal of Forest Research*, 28: 331–339.
Brose, P., Van Lear, D., and Cooper, R. 1999. Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites. *Forest Ecology and Management*, 113: 125–141.
Brose, P. H., Van Lear, D. H., and Keyser, P. D. 1999. A shelterwood–burn technique for regenerating productive upland oak sites in the Piedmont region. *Southern Journal of Applied Forestry*, 23: 158–163.
Burton, P. J., Sutherland, D. C., Daintith, N. M., Waterhouse, M. J., and Newsome, T. A. 2000. *Factors Influencing the Density of Natural Regeneration in Uniform Shelterwoods Dominated by Douglas-fir in the Sub-Boreal Spruce Zone* (No. 47). Ministry of Forests, British Columbia.
Clinton, B. D., Boring, L. R., and Swank, W. T. 1994. Regeneration patterns in canopy gaps of mixed-oak forests of the southern Appalachians: influences of topographic position and evergreen understory. *American Midland Naturalist*, 132: 308–319.
Crow, A. B. and Shilling, C. L. 1980. Use of prescribed burning to enhance southern pine timber production. *Southern Journal of Applied Forestry*, 4: 15–18.
Donoso, P. J. and Nyland, R. D. 2006. Interference to hardwood regeneration in Northeastern North America: the effects of raspberries (*Rubus* spp.) following clearcutting and shelterwood methods. *Northern Journal of Applied Forestry*, 23: 288–296.
Ferguson, D. E. and Adams, D. L. 1980. Response of advance grand fir regeneration to overstory removal in northern Idaho. *Forest Science*, 26: 537–545.
Fladeland, M. M., Ashton, M. S., and Lee, X. 2003. Landscape variations in understory PAR for a mixed deciduous forest of southern New England. *Agricultural and Forest Meteorology*, 118: 137–141.
Frey, B., Ashton, M. S., McKenna, J., Ellum, D., and Finkral, A. 2007. Topographic-related patterns in seedling establishment, growth, and survival among masting species of Southern New England hardwood forests. *Forest Ecology and Management*, 244: 31–45.
Funk, D.T. (ed.). 1986. *Eastern White Pine: Today and Tomorrow*. USFS General Technical Report. WO-51, 124 p.
Gardiner, E. S. and Hodges, J. D. 1998. Growth and biomass distribution of cherrybark oak (Quercus pagoda Raf.) seedlings as influenced by light availability. *Forest Ecology and Management*, 108: 127–134.
Godman, R. M. and Tubbs, C. H. 1973. *Establishing Even-Age Northern Hardwood Regeneration by the Shelterwood Method – a Preliminary Guide*. USDA Forest Service Research Paper, North Central Forest Experiment Station (NC-99).
Greene, D. F., Zasada, J. C., Sirois, L., Kneeshaw, D., Morin, H., Charronand, I., and Simard, M. J. 1999. A review of the regeneration dynamics of North American boreal forest tree species. *Canadian Journal of Forest Research*, 29: 824–839.
Hannah, P. R. 1988. The shelterwood method in northeastern forest types. *Northern Journal of Applied Forestry*, 8: 99–104
Harmer, R., Boswell, R., and Robertson, M. 2005. Survival and growth of tree seedlings in relation to changes in the ground flora during natural regeneration of an oak shelterwood. *Forestry*, 78: 21–32.
Healy, W. M., Lewis, A. M., and Boose, E. F. 1999. Variation of red oak acorn production. *Forest Ecology and Management*, 116: 1–11.
Helms, J. A. and Standiford, R. B. 1985. Predicting release of advance reproduction of mixed conifer species in

California following overstory removal. *Forest Science*, 31: 3–15.
Holmes, C. H. 1957. The natural regeneration of wet and dry evergreen forests of Ceylon. *Ceylon Forester*, 3: 15–41.
Horsley, S. B. 1994. Regeneration success and plant species diversity of Allegheny hardwood stands after Roundup application and shelterwood cutting. *Northern Journal of Applied Forestry*, 11: 109–116.
Horsley, S. B. and Marquis, D. A. 1983. Interference by weeds and deer with Allegheny hardwood reproduction. *Canadian Journal of Forest Research*, 13: 61–69.
Johnson, P. S., Shifley, S. R., and Rogers, R. 2009. *The Ecology and Silviculture of Oaks*. CABI, Wallingford, UK.
Joshi, H. B. 1980. (ed.) *Silviculture of Indian Trees*. Vol. II. Forest Research Institute Press, Dehra Dun. 471 p.
Kellison, R. C. and Young, M. J. 1997. The bottomland hardwood forest of the southern United States. *Forest Ecology and Management*, 90: 101–115.
Kelty, M. J. and Nyland, R. D. 1981. Regenerating Adirondack northern hardwoods by shelterwood cutting and control of deer density. *Journal of Forestry*, 79: 22–26.
Leak, W. B. and Tubbs, C. H. 1983. *Percent Crown Cover Tables for Applying the Shelterwood System in New England*. USDA Forest Service, Research Note NE-313.
Leak, W. B., Solomon, D. S., and DeBald, P. S. 1987. *Silvicultural Guide for Northern Hardwood Types in the Northeast (revised)*. USFS Research Paper. NE-603, 40 pp.
Lockhart, B. R., Hodges, J. D., and Gardiner, E. S. 2000. Response of advance cherrybark oak reproduction to midstory removal and shoot clipping. *Southern Journal of Applied Forestry*, 24: 45–50.
Loftis, D. L. 1983. Regenerating southern Appalachian mixed hardwood stands with the shelterwood method. *Southern Journal of Applied Forestry*, 7: 212–217.
Loftis, D. L. 1990. A shelterwood method for regenerating red oak in the southern Appalachians. *Forest Science*, 36: 917–929.
Lowe, R. G. 1977. Experience with the tropical shelterwood system of regeneration in natural forest in Nigeria. *Forest Ecology and Management*, 1: 193–212.
Man, R. and Lieffers, V. J. 1999. Effects of shelterwood and site preparation on microclimate and establishment of white spruce seedlings in a boreal mixedwood forest. *Forestry Chronicle*, 75: 837–844.
Marquis, D. A. 1966. *Germination and Growth of Paper and Yellow Birch in Simulated Strip Cuttings*. USFS Research Paper. NE-54 19 pp.
Marquis, D. A. 1979. Shelterwood cutting in Allegheny hardwoods. *Journal of Forestry*, 77: 140–144.
Martin, A. J. and Hix, D. M. 1988. Regeneration development in an upland hardwood stand following a shelterwood harvest. *Northern Journal of Applied Forestry*, 5: 46–49.
McDonald, P. M. 1976. *Shelterwood Cutting in a Young-Growth Mixed-Conifer Stand in North Central California*. USDA Forest Service Research Paper, Pacific Southwest Forest and Range Experiment Station, PSW-117.
Moser, W. K., Ducey, M. J., and Ashton, P. M. S. 1996. Effects of fire intensity on competitive dynamics between red and black oaks and mountain laurel. *Northern Journal of Applied Forestry*, 13: 112–118.
Nicholson, D. I. 1979. *The Effects of Logging and Treatment on the Mixed Dipterocarp Forests of Southeast Asia*. FAO Rome, 65 pp.
Nilsson, U., Gemmel, P., Johansson, U., Karlsson, M., and Welander, T. 2002. Natural regeneration of Norway spruce, Scots pine and birch under Norway spruce shelterwoods of varying densities on a mesic-dry site in southern Sweden. *Forest Ecology and Management*, 161: 133–145.
Oliver, C. D., Clatterbuck, W. K., and Burkhardi, E. C. 1990. Spacing and stratification patterns of cherrybark oak and American sycamore in mixed, even-aged stands in the southeastern United States. *Forest Ecology and Management*, 31: 67–79.
Oliver, C. D., Burkhardt, E. C., and Skojac, D. A. 2005. The increasing scarcity of red oaks in Mississippi River floodplain forests: influence of the residual overstory. *Forest Ecology and Management*, 210: 393–414.
Petersen, T. D., Newton, M., and Zedaker, S. M. 1988. Influence of Ceanothus velutinus and associated forbs on the water stress and stemwood production of Douglas-fir. *Forest Science*, 34: 333–343.
Pothier, D. and Prevost, M. 2008. Regeneration development under shelterwoods in a lowland red spruce-balsam fir stand. *Canadian Journal of Forest Research*, 38: 31–39.
Prévosto, B., Monnier, Y., Ripert, C., and Fernandez, C. 2011. Can we use shelterwoods in Mediterranean pine forests to promote oak seedling development? *Forest Ecology and Management*, 262: 1426–1433.
Puettmann, K. J., D'Amato, A. W., Kohnle, U., and Bauhus, J. 2009. Individual-tree growth dynamics of mature *Abies alba* during repeated irregular group shelterwood (Femelschlag) cuttings. *Canadian Journal of Forest Research*, 39: 2437–2449.
Ray, D. G., Nyland, R. D., and Yanai, R. D. 1999. Patterns of early cohort development following shelterwood cutting in three Adirondack northern hardwood stands. *Forest Ecology and Management*, 119: 1–11.
Raymond, P., Bédard, S., Roy, V., Larouchеand, C., and Tremblay, S. 2009. The irregular shelterwood system: review, classification, and potential application to forests affected by partial disturbances. *Journal of Forestry*, 107: 405–413.

Ruel, J. C., Raymond, P., and Pineau, M. 2003. Windthrow after shelterwood cutting in balsam fir stands. *Northern Journal of Applied Forestry*, 20: 5–13.

Sander, I. L. 1979. Regenerating oaks with the shelterwood system. In: *Proceedings, Regenerating Oaks in Upland Hardwood Forests*. John S. Wright Forestry Conference. pp. 54–60.

Schuler, T. M. and Miller, G. W. 1995. Shelterwood treatments fail to establish oak reproduction on mesic forest sites in West Virginia-10-year results. In: Gottschalk, K. W. and Fosbroke, S. L. C.. (eds.). *Proceedings, 10th Central Hardwood Forest Conference; 1995 March 5–8*. Morgantown, W. V. USDA General Technical Report. NE-197.

Seidel, K. W. 1983. *Regeneration in Mixed Conifer and Douglas-fir Shelterwood Cuttings in the Cascade Range of Washington*. USDA Forestry Service Research Paper. PNW-314. 17 pp.

Seidel, K. W. and Cooley, R. 1974. *Natural Reproduction of Grand Fir and Mountain Hemlock after Shelterwood Cutting in Central Oregon* (Vol. 229). US Dept. of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station.

Seymour, R. S. 1992. The red spruce-balsam fir forest of Maine: evolution of silvicultural practice in response to stand development patterns and disturbances. In: M. J. Kelty, C. D. Oliver, and B. C. Larson (eds.). *The ecology and silviculture of mixed-species forests*. Springer-Verlag, The Netherlands. pp. 217–244.

Sist, P. and Nguyen-The, N. 2002. Logging damage and the subsequent dynamics of a dipterocarp forest in east Kalimantan (1990–1996). *Forest Ecology and Management*, 165: 85–103.

Verissimo, A., Barreto, P., Tarifa, R., and Uhl, C. 1995. Extraction of a high-value natural resource in Amazonia: the case of mahogany. *Forest Ecology and Management*, 72: 36–60.

Williamson, R. L. 1973. *Results of Shelterwood Harvesting of Douglas-fir in the Cascades of Western Oregon*. USFS Research Paper. PNW 161. 13 pp.

Wyatt-Smith, J. 1963. *Manual of Malayan Silviculture for Inland Forests* (2 Vols.). Malay Forest Records No. 23, Forest Research Institute, Kepong, Malaysia.

Youngblood, A. 1990. Effects of shelterwood removal methods on established regeneration in interior Alaska white spruce. *Canadian Journal of Forest Research*, 20: 1378–1381.