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Clearcut and Shelterwood Reproduction Methods for Regenerating Southwest Oregon Forests

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English/metric conversions

1 foot x 0.305 = 1 m

1 inch x 2.54 = 1 cm

0.555 (1°F - 32) = 1°C

1 acre x 0.405 = 1 ha

1 ft^2/acre x 0.23 = 1 m^2/ha

1 bd ft x 0.00236 = 1 m^3

1 bd ft/acre x 0.0058 = 1 m^3/ha

NOTE: Board foot and board foot per acre are based on nominal measurement (1 inch x 1 foot x 1 foot), not on actual measurement derived from scaling.

Abbreviations

BLM	Bureau of Land Management
SEV	Soil expectation value
NPV	Net present value
NPA	Net present amount
dbh	Diameter at breast height (4.5 feet above ground line)
M bd ft	Thousand board feet

Executive Summary

Clearcut and shelterwood reproduction methods—that is, the harvest and post-harvest treatments that favor seedling establishment and growth—are important, silviculturally sound forest-management tools for southwest Oregon. The ecology of the forests in the region lends itself to the successful application of either method, in most cases. Choice of method, then, is usually based on land management objectives—which integrate factors such as diverse resource and societal values, economics, legal and regulatory guidelines, and administrative considerations, and which vary according to type of ownership (public agency, private industry, small nonindustrial private landowner).

This report summarizes the available information on the clearcut and shelterwood reproduction methods so that land managers can understand the trade-offs between the two. We assume, for purposes of discussion, that timber production is the primary land-management objective; however, most of the information presented herein can be extrapolated to other objectives as well.

Both reproduction methods lead to the development of even-aged stands. In even-aged regimes, all tree age classes typically fall within a range of years not exceeding 20 percent of the expected lifespan of the stand. In uneven-aged regimes, trees are of three or more distinct age classes. The clearcut method, in which all trees are removed during one harvest entry, fully exposes the forest floor to allow establishment of a new stand by artificial regeneration (planting of seedlings or direct seeding) or natural regeneration. The shelterwood method, in which trees are removed over at least two harvest entries, retains some larger trees ("the shelterwood") to provide canopy protection for seedlings and a source of seed; once seedlings have been established by artificial or natural regeneration, the overstory is removed to enhance seedling growth.

The report focuses on the interior valley zone in southwest Oregon—bordered on the west, southwest, and east by the Coast Range, Siskiyou Mountains, and Cascade Range, respectively, to the north by the Roseburg area, to the south by the California border. Within this region, artificial regeneration by planting seedlings is the dominant reforestation approach; indeed, most shelterwoods on commercially managed lands are planted, as are virtually all clearcuts. Natural regeneration has not been a primary reforestation approach for most agency or industry landowners because they cannot with certainty rely on it to promptly meet reforestation objectives; however, natural regeneration can be significant in some situations and therefore is discussed. This report focuses on Douglas-fir (*Pseudotsuga menziesii*)—most foresters' species of choice and the one most often planted in the region—but includes information, where known, on other species.

We highlight in the listing below the key points distilled from comparing the clearcut and shelterwood reproduction methods and then present a summary table (pages 2 and 3) that arrays the factors compared.

- Once land management objectives are established, site-specific silvicultural prescriptions are critical because of environmental diversity and varying stand conditions. All operations should be carefully planned before a stand is ever entered.
- For sites not prone to growing-season frosts, research results and operational experience indicate that clearcut and shelterwood methods can produce nearly equal seedling survival when a quality artificial-regeneration program is implemented and competing vegetation is controlled, as long as the shelterwood overstory can be removed without substantial mortality of established seedlings.
- Study results suggest that site preparation and control of competing vegetation are often more critical for the survival of planted seedlings than is overstory shade, particularly on droughty, low-elevation sites. On such sites, vegetation control is typically necessary for successful reforestation regardless of reproduction method.
- Using the shelterwood method with natural regeneration can be a valuable option when objectives call for less intensive management or minimum investment in reforestation, or when an extended regeneration period is acceptable.
- The shelterwood method can be beneficial on hot south or west aspects when relatively small container-grown seedlings will be planted.
- For sites prone to growing-season frosts, species selection strongly influences choice of reproduction method. Shelterwood management helps to promote frost-sensitive species such as Douglas-fir or white fir (*Abies concolor*), whereas clearcutting may limit reforestation to frost-tolerant species such as lodgepole, ponderosa, or western white pine (*Pinus contorta*, *P. ponderosa*, or *P. monticola*).
- Recent studies indicate that, regardless of reproduction method, Douglas-fir seedlings and saplings are capable of recovering from many kinds

Factor for comparison	Reproduction method	
	Clearcut (CC)	Shelterwood (SW)
Reforestation success		
Hot, droughty sites	Success potentially good with vegetation management and good planting practices	Success potentially good with vegetation management and good planting practices
Frosty sites	Success limited to frost-hardy species	Success better than with CC for frost-sensitive species
Moderate sites	Success probably good	Success probably good; canopy unnecessary for success
Reforestation flexibility	Less flexibility than with SW for natural regeneration; fill-in planting possible for understocked areas	More flexibility than with CC for natural regeneration with seedtrees in place; fill-in planting possible for understocked areas before and after overstory removal
Potential for additional stocking, species diversity from natural regeneration	Less potential than with SW, particularly if CC is large and seed dissemination from nearby areas difficult	Greater potential than with CC; overstory trees on site produce seed, protect natural seedlings; overstory trees can be selected to retain diversity, if it exists in uncut stand
Seedling growth rate	Maximum rate	Slower rate than with CC with overstory in place, particularly for shade-intolerant species; correlated with overstory density, length of time overstory is retained
Seedling competition with overstory trees	None; overstory removed before planting	Considerable competition until overstory removed; correlated with overstory density
Risk of "blowdown" of residual overstory trees	None within unit	Variable risk, depending on terrain
Potential for pathogen and insect problems	Potential often less than with SW	Potential often greater than with CC because of multiple entries, residual-tree damage, and possibility of infecting new understory from overstory
Effect on soil biology	Generally no significant effect with prompt reforestation; most effects due to selected site-preparation and vegetation-management practices	Generally no significant effect with prompt reforestation; most effects due to selected site-preparation and vegetation-management practices
Potential for waterlogged soils in wet areas	Greater potential than with SW because overstory removed	Less potential than with CC because overstory trees retained transpire water
Potential for soil exposure, displacement, compaction	Less potential than with SW; but generally the same with prompt reforestation because of single entries and use of skidtrails on tractor-logged areas	Greater potential than with CC because of multiple entries; otherwise, the same as for CC with prompt reforestation, use of designated skidtrails on tractor-logged areas
Potential for creating or exacerbating long-term vegetation management problems	Potential tends to be high, depending on plant association, environment; but site fully exposed for treatment	Potential variable, depending on canopy density, plant association, environment
Aesthetic quality	Quality poorer than with SW initially, but potentially faster vegetation recovery	Quality better than with CC until overstory removed, then similar to that of CC (unless overstory is retained until seedlings are large); logging corridors may be evident after overstory removal
Potential for long-term yield	Potential similar to that with SW, assuming prompt seedling establishment; greater opportunity for efficient intensive management	Potential similar to that with CC unless poor-vigor overstory is retained and seedling growth reduced

Factor for comparison	Reproduction method	
	Clearcut (CC)	Shelterwood (SW)
Area cutover to obtain equal timber volume/ entry	Less area with CC	Greater area with SW; may have negative aesthetic impact if contiguous areas are large and seedlings small
Operational flexibility	Greater flexibility than with SW because no overstory or establishing seedlings need to be protected	Less flexibility than with CC because multiple entries require overstory and seedlings to be protected; protection especially difficult on steep terrain
Logging cost		
Steep terrain	Cost lower than with SW	Cost higher than with CC
Gentle terrain	Cost slightly lower than with SW	Cost slightly higher than with CC
Yarding		
Steep terrain:		
Uphill skyline	Easy	Difficult
Downhill skyline	Easy	Not recommended
High lead	Easy	Not recommended
Helicopter	Easy	Moderate
Gentle terrain:		
Tractor	Easy	Moderate
Slash disposal		
Prescribed fire	Less difficult than with SW	More difficult than with CC because overstory must be protected
Yarding, piling unmerchantable material:		
Steep terrain	Slightly less difficult than with SW	More difficult than with CC; potential for introducing pathogens into overstory
Gentle terrain	Less difficult than with SW	More difficult than with CC; potential for introducing pathogens into overstory
Vegetation management (site preparation, release)		
Chemical:		
Aerial	Less difficult than with SW	More expensive, less effective than with CC because overstory reduces spray coverage, can cause safety hazard; after overstory removal, difficulty similar to that with CC
Tractor sprayer	Less difficult than with SW	Somewhat more difficult than with CC
Backpack	Easy	Easy
Mechanical:		
Steep terrain	Slightly less difficult than with SW, but expensive	Very difficult, expensive
Gentle terrain	Easy	More difficult than with CC; after overstory removal, difficulty similar to that with CC
Work-force requirements	Requirements low	Requirements greater than with CC because of multiple entries
Skill level of work force	Less skill required than with SW to plan, implement this single-entry method that does not require tree marking	More experience, greater skill required than with CC to select residual overstory; to plan to protect overstory and established seedlings; to coordinate silvicultural, harvesting objectives
Timber-sale administration cost	Cost lower than with SW	Cost higher than with CC

of logging damage to become crop trees within 5 years of injury.

- The classical shelterwood method is not a panacea for addressing long-term aesthetic concerns. Removing overstory trees within 5 years of planting leaves a site that appears much like a clearcut of equal age. Retaining the overstory until seedlings are larger provides greater aesthetic benefits and more complex stand structure for wildlife habitat, but typically results in seedling growth losses and greater potential for seedling damage during overstory removal.
- The increased complexity and cost associated with the shelterwood method must be recognized and a management commitment made to provide the necessary resources for success.

Chapter 1: Introduction

Selection of forest regeneration practices depends upon ecological, operational, economic, and sociopolitical opportunities and constraints (Greaves *et al.* 1978). In the interior valley region we call southwest Oregon (Figure 1), shifts in the balance among these factors over the last half century have several times caused timber-harvest and reproduction methods to change, most noticeably on public lands.

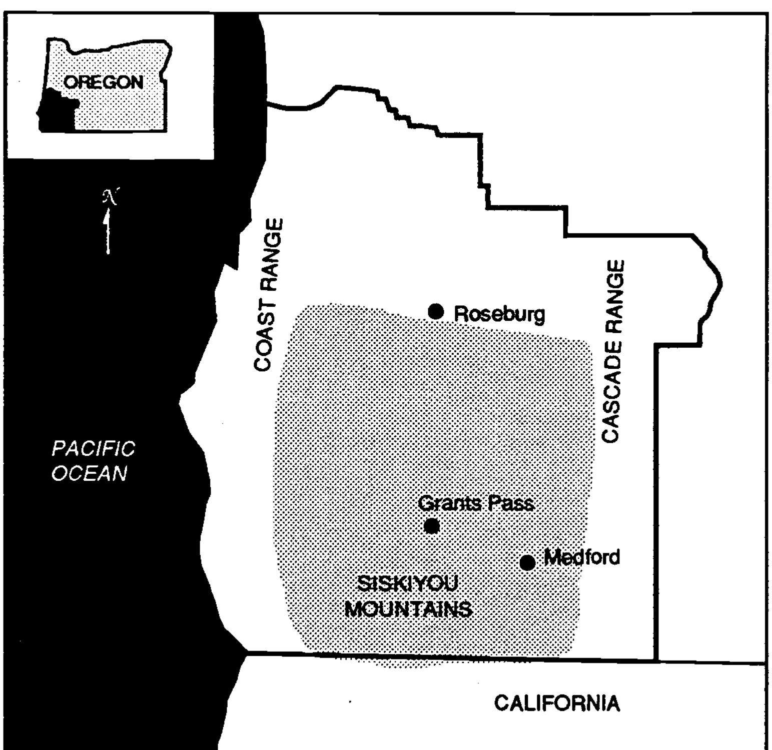

Figure 1. Southwest Oregon, the study area (shaded oblong).

Much of southwest Oregon is considered difficult to regenerate after timber harvest because of hot, dry summers and prolific competing vegetation (Owston and Lavender 1979, Hobbs *et al.* 1983, Walstad and Tesch 1987). However, in this region the choice of reproduction method—that is, the harvest and post-harvest treatments that favor seedling establishment and growth (Smith 1986)—is strongly influenced by landowner objectives because the diverse terrain and forest types rarely mandate selection of one method over another.

The goal of this bulletin is to compare the clearcut and shelterwood reproduction methods as tools for forest regeneration in southwest Oregon.[1] We recognize that regeneration-related activities also affect elements of the forest ecosystem such as air, water, and wildlife; however, in-depth discussion of such issues is beyond the scope here. We assume, for purposes of this report, that the primary resource objective is reforestation for timber production.

Both reproduction methods lead to the development of even-aged stands. In even-aged stands, all tree age classes typically fall within a range of years not exceeding 20 percent of the expected lifespan of the stand; for example, if stand lifespan is 100 years, then all trees would be within 20 years in age of one another. In uneven-aged stands, trees are of three or more distinct age classes. The clearcut reproduction method, in which all trees are removed during one harvest entry, fully exposes the forest floor to allow establishment of a new stand by artificial regeneration (planting of seedlings or direct

[1] Unfortunately, there is room for confusion when defining the terms "clearcut" and "shelterwood" because each may refer to a harvest strategy, a reproduction method, or a silvicultural system. Because the focus here is on reforestation, we intend these terms as reproduction methods.

seeding) or natural regeneration. The shelterwood reproduction method, in which trees are removed over at least two harvest entries, retains some larger trees ("the shelterwood") to provide canopy protection for seedlings and a source of seed; once seedlings have been established by artificial or natural regeneration, the remaining overstory trees are removed to enhance seedling growth.

In this bulletin, we describe the region's environment and outline its reforestation history (Chapter 2). We characterize reproduction methods (Chapter 3) and lay the groundwork both for discussing ecological principles (Chapter 4) and for reviewing results of published and unpublished studies (Chapter 5). Although artificial regeneration by planting seedlings is currently the dominant reforestation approach in the region, natural regeneration has been relied upon and studied in the past; thus, our discussions reflect the results of both. We examine operational considerations that influence a manager's ability to implement selected reproduction methods (Chapter 6) and compare the economic efficiency over time of clearcut and shelterwood methods through cash-flow analyses from three example timber sales (Chapter 7). Finally, we suggest a decision-making and planning framework for managers to help assure regular reforestation success (Chapter 8) and draw some conclusions about the viability of the clearcut and shelterwood reproduction methods for regenerating southwest Oregon forests (Chapter 9).

Chapter 2: Regional Environment and Reforestation History

Environment

The mountainous physiography of the area is complex and varied. Topography is steep and dissected in the western half, nearly flat in some parts of the southern Cascades. Soils are often thin and gravelly, and may be derived from volcanic, sedimentary, or metamorphic rocks (McDonald *et al.* 1983). From 1000 to 7000 feet in elevation, precipitation ranges from about 20 to 100 inches annually (Froehlich *et al.* 1982), with only 4 to 9 inches from May through September (McNabb *et al.* 1982). The prolonged summer drought is accompanied by temperatures often approaching 100°F (Gratkowski 1961, Minore and Kingsley 1983). Such diverse topography, soil parent material, and weather lead to an extremely diverse flora.

Most of the commercial forest land lies in the mixed-evergreen and mixed-conifer zones (Whittaker 1960, Franklin and Dyrness 1973). The mixed-conifer forests vary in composition, with two or more of the following major species nearly always present: Douglas-fir (*Pseudotsuga menziesii*), incense-cedar (*Calocedrus decurrens*), sugar pine (*Pinus lambertiana*), white fir (*Abies concolor*), and ponderosa pine (*Pinus ponderosa*). Jeffrey pine (*Pinus jeffreyi*) is common on ultramafic soils in the Siskiyous. Grand fir (*Abies grandis*) hybridizes with white fir in the Cascades, red fir (*Abies magnifica*) is found at higher elevations, and lodgepole pine (*Pinus contorta*) occurs in frost-prone areas and at higher elevations in the Cascades with mountain hemlock (*Tsuga mertensiana*).

Southwest Oregon forests also contain a variety of hardwood tree species and both deciduous and sclerophyllous shrub species (McDonald *et al.* 1983). Tanoak (*Lithocarpus densiflorus*) and madrone (*Arbutus menziesii*) are two common hardwood trees that sprout vigorously after disturbance, as do others such as canyon live oak (*Quercus chrysolepis*) and chinkapin (*Castanopsis chrysophylla*). Shrubs, typified by manzanita (*Arctostaphylos* spp.), ceanothus (*Ceanothus* spp.), and poison oak (*Toxicodendron diversilobum*), may sprout or germinate from seed stored in the soil to rapidly occupy sites after disturbance. Grasses and other herbaceous plants are also an important component of some forest types (McDonald 1986).

History

Harvest methods evolved from selective cutting of individual trees in small groups to clearcutting of larger areas in the late 1950s, probably to enhance harvesting economy (Minore 1978, Strothmann and Roy 1984). At the time, natural regeneration was commonly relied upon, although some sites were artificially regenerated. Site preparation after logging varied from none at all to intense broadcast burning; however, harvest methods such as high-lead yarding sometimes adequately prepared the site. Government-agency records show that policies in the 1960s frequently mandated waiting 3 to 5 years for natural regeneration before artificial regeneration was attempted (Minore 1978); apparently, however, the developing competing vegetation was seldom controlled before the delayed attempts at artificial regeneration were begun.

By the mid-1960s, foresters recognized problems with the ongoing application of clearcutting—a common perception was that clearcut sites became too hot and dry for seedlings to survive. They turned instead to "partial cutting," a generic term we use to encompass all harvest practices that leave some overstory trees and for which specific objectives are unclear; with partial cutting, natural regeneration or direct seeding was typically relied upon initially to establish a new stand. However, site preparation and control of competing vegetation became more difficult under the residual canopy, especially on steep sites where burning or aerial application of herbicides was difficult and less effective. As a result, sites were often occupied by competing vegetation before overstory trees had good seed years, and regeneration in partial cuts was not predictably prompt.

The generic term "partial cutting," rather than "shelterwood management," is appropriate for most sites regenerated under canopy shade before the mid-1970s because of limited documentation of foresters' objectives, the wide array of initial stand conditions encountered, and differences in harvest timing and intensity. Indeed, in some cases, it was unclear whether the goal was even- or uneven-aged management (Stein 1986).

But concerns over harvesting and reforestation practices intensified in the mid-1970s, when pressure for more prompt reforestation of both clearcut and partially cut areas increased—partly from the public and partly as a result of forestry-related state and federal policy and legislation. This intensified focus helped shape true shelterwood management by stimulating improvements in reforestation practices and encouraging land managers to better define objectives and plan treatments. Foresters found that planting beneath shelterwood canopies promoted more rapid seedling establishment than waiting for natural regeneration, but that costs increased as intensity of reforestation practices increased.

By the late 1970s, reforestation technology and practice began to improve substantially. Nursery improvements generally led to better seedling quality. The need for careful planting on well-prepared sites was recognized, as was the need for follow-up plantation maintenance to control competing vegetation and animal damage. Research results began to demonstrate that intensive reforestation practices could lead to good seedling survival with clearcutting. In fact, by the early 1980s, both operational and research results showed respectable survival with either clearcutting or shelterwood practices when artificial regeneration was used (Tables 1, 2).

Table 1. Percentage of planted Bureau of Land Management (BLM) acres meeting stocking targets on sites regenerated with the clearcut and shelterwood reproduction methods, as determined from periodic stocking surveys (data provided by the District Silviculturist, Medford District BLM).

Method, by survey date	1-year-old plantations			3-year-old plantations		
	AT[1]	BT/AM	BM	AT	BT/AM	BM
	—% of acres planted—					
Fall 1981						
Clearcut	81	5	14	—[2]	—	—
Shelterwood	56	35	9	—	—	—
Fall 1983						
Clearcut	88	2	10	67	14	19
Shelterwood	78	4	18	78	4	14
Fall 1985						
Clearcut	77	6	17	80	10	10
Shelterwood	76	12	12	68	16	16

[1]AT: at or above target; BT/AM: below target, but above minimum (acceptable); BM: below minimum, need to replant.

[2]Formal surveys not completed.

Table 2. Average seedling survival of the most successful species-stocktype treatment[1] on regenerated clearcuts or brushfields located on hot, dry, and often steep sites as of January 1, 1990, after 5 years of observation (Tesch *et al.* 1990b).

Site name	Aspect	Slope (%)	Elevation (ft)	Annual precipitation (in.)	Survival[2] (%)	Species[3]	Comments
Myrne Return	N	58	3500	85	81	DF	
Rocky Ravel	N	80	3600	78	81	DF	
Dutch Herman #1	N	23	3800	59	84	DF	
Dutch Herman #2	N	40	3400	59	89	DF	
Hog Remains	N	80	2800	46	88	DF	
Millcat	N	35	2000	38	83	DF (PP)	
Blue Gulch	N	68	2000	35	99	PP	
Burton Butte	N	67	3000	26	95	PP (DF)	
Marial Ridge	S	18	2500	82	82	DF	
Julie Creek	S	27	3000	75	77	(DF)	Bracken fern competition
Walker Return	S	70	2200	72	82	DF	
Peggler Butte	S	32	3400	60	45	(DF)	
Brandt Crossing	S	60	1300	52	92	PP (DF)	
Steven's Creek	S	50	2000	47	90	DF, PP	
Buckhorn #1	S	68	2600	45	73	(DF, PP)	Herbaceous competition
Limp Hog	S	58	2200	45	45	(PP,DF)	Grass competition
Miller Gulch	S	49	2000	45	25	(PP)	Porcupine damage
Pickett Again	S	55	2800	42	83	DF, PP	
Wolf Gap	S	50	3800	40	83	DF	
Forest (Oregon) Belle	S	50	2900	40	81	PP	
Chrome Umbrella	S	45	3200	37	96	DF	
Rock Creek	S	65	2700	33	68	(DF, PP)	
Negro Ben	S	50	3700	30	98	PP (DF)	
Salt Creek	S-SW	48	3000	24	92	PP, DF	
West Left Fielder	W	35	2800	40	81	DF (PP)	
Texter Gulch	W	33	2900	35	94	DF, PP	
Tin Pan Peak	W	35	1350	30	98	PP, DF	

[1] As many as three species-stocktype treatments were possible on a given site for Douglas-fir, including 1+0 plugs, 2+0 bareroots, and plug +1s; two were possible for ponderosa pine, 1+0 plugs and 2+0 bareroots. Not all combinations occurred on all sites.

[2] Survival at the end of 5 years; each value is the average of three replications of the most successful treatment.

[3] DF = Douglas-fir; PP = ponderosa pine. Key to understanding "species" column:
species name(s): species with average survival exceeding 80 percent.
(species): species noted in parentheses was at the test site, but no stocktype exceeded 80-percent survival.

Chapter 3: Even-Aged Reproduction Methods—Classification and Considerations

Reproduction methods promoting even-aged stand establishment are classified as clearcut, seedtree, and shelterwood. The classification implies three distinct and separate methods; however, the three really represent positions on a continuum, with seemingly infinite modifications of each possible to meet specific situations (Daniel *et al.* 1979).

Classical definitions separate the methods on the basis of number of entries to remove the mature stand, control over distribution of seed when natural regeneration is used,[2] and degree of site exposure. Clearcutting removes the mature stand in one entry, maintains the poorest control of seed distribution, and allows the greatest exposure of seedlings during the regeneration period. Shelterwood practices require two or three entries, but provide greater control of seed distribution and the most site protection. The seedtree method, which leaves 5 to 10 trees per acre, is intermediate between the other two. Used primarily to improve distribution of seed in naturally regenerated units, this method is seldom implemented in southwest Oregon and therefore will not be discussed here. All three reproduction methods expose developing seedlings to full sunlight for most of the rotation. Ecological, operational, and economic considerations associated with the use of the clearcut and shelterwood methods are detailed in the following box.

[2] In southwest Oregon today, most harvest units on industry and agency land—including shelterwoods—are planted with seedlings to improve on unpredictable seed crops and poor survival of germinants.

Clearcut Method

Ecological Considerations:

- With site preparation, available soil moisture is usually greater in clearcuts because seedlings do not have to compete with overstory trees. However, rapid development of competing vegetation may necessitate follow-up vegetation management to ensure reforestation success.
- Prompt natural regeneration can be difficult because of problems with seed dispersal into large harvest units.
- Clearcut sites are fully exposed to temperature extremes, unless harvest units are small enough that overstory trees at the edge of the adjacent stand can provide protection. Such exposure may be detrimental to naturally germinating seedlings.
- Clearcuts on flatter, high-elevation sites can be difficult to regenerate because of frost, unless frost-resistant species are planted.

Operational and Economic Considerations:

- Clearcutting is the easier method to plan, implement, and administer—all operations are concentrated in time and space.
- Because no overstory trees or seedlings need to be protected, logging costs per unit area are relatively low, and operations such as slash disposal, site preparation, and later release treatments are relatively easy to perform.
- Clearcutting offers more operational flexibility, especially on steep terrain, but may offer less reforestation flexibility over time because harvesting the entire stand reduces future options for natural regeneration and site protection.
- Less area is cutover each year with the clearcut than shelterwood method to meet a specific harvest-volume goal.
- On first entry of a watershed, fewer miles of road must be built and maintained to obtain an equal volume of timber for the clearcut than shelterwood method (Williamson and Twombly 1983). However, over longer periods, multiple-use considerations, economics, and logging feasibility probably result in comparable transportation systems for both methods.
- Clearcutting is commonly regarded by the public as aesthetically displeasing for at least the first 5 years after harvest.

Shelterwood Method

Ecological Considerations:

- On environmentally extreme (hot or cold) sites, the shelterwood canopy moderates the forest-floor microenvironment and can improve initial survival of both planted and naturally regenerated seedlings.
- A shelterwood can improve seed availability and distribution within a harvest unit and thus promote natural regeneration. However, it provides little control over the timing and density of naturally regenerated seedlings—overstocking and understocking are possibilities.
- Residual overstory trees can be selected to promote species diversity and provide an on-site seed source that may be adapted to adverse site conditions.
- Shelterwood practices increase the potential for root rot and other pathogens when overstory trees are damaged during the first harvest entry.
- Seedlings on shelterwood units may be smaller than those of the same age on clearcuts because of the suppressive effect of the overstory—for instance, residual overstory trees compete with planted seedlings for stored soil water.
- Shelterwood management may help prevent waterlogged or saturated soils on some sites (USDA Forest Service 1979).
- Shelterwoods can provide protection from frost on relatively flat, high-elevation sites where frost-sensitive species are difficult to regenerate after clearcutting.
- Risk of overstory trees being toppled by wind ("blowdown") must be considered.
- Site preparation and follow-up vegetation management are usually necessary with the shelterwood method to ensure reforestation success.

Operational and Economic Considerations:

- Shelterwood management requires protection of 10 to 20 residual overstory trees per acre during the first harvest entry, and of established seedlings during overstory removal later on.
- Other site resources, such as the soil, also must be protected over at least two harvest entries.
- Protecting site resources requires a larger work force, more highly trained personnel, and closer supervision of logging operations.
- Because of multiple entries and the need for site protection, logging costs typically are higher for shelterwoods than for clearcuts, particularly on steep ground where skyline or helicopter logging is required.
- Shelterwoods reduce the visual impact of the regeneration cut. But overstory removal within 5 years often leads to the same aesthetically displeasing conditions as does clearcutting, particularly on poorer sites where tree growth is slower.
- When variants of the classical shelterwood method are designed to retain the overstory for a prolonged period to enhance aesthetics or wildlife habitat, foresters should anticipate slower seedling growth, more damage to larger seedlings during overstory removal, and generally more difficult and expensive harvesting techniques. Overall stand growth, however, may be acceptable when vigorous overstory trees capable of responding to release are selected for the shelterwood.

Chapter 4: Ecological Considerations for Selecting a Reproduction Method

Successful reforestation is achieved by matching silvical characteristics of desired species with environmental and biological attributes of a forest site. Reproduction methods can modify site conditions within broad ecological limits and enhance the match between tree species and site, particularly during the seedling establishment period when sensitivity to abiotic and biotic elements is great. Because reforestation success is a function of "macroenvironment" (conditions of the site as a whole) and "microenvironment" (conditions faced by individual conifer seedlings), reforestation planners can improve their chances for success by assembling as much pertinent site information as possible before beginning operations.

It is possible to directly measure many environmental variables, but it is usually impossible to obtain a representative sample of factors such as temperature and moisture on all sites. Plant-community or environmental classification systems are useful tools for characterizing the site, and can provide important clues to events like growing-season frosts or summer drought. Minore and others have classified environments and suggested management implications based on soil, topography, and presence of indicator plant species for several areas of southwest Oregon (Minore 1972, Carkin and Minore 1974, Minore and Carkin 1978, Graham *et al.* 1982, Minore *et al.* 1982a, Minore *et al.* 1982b). The plant-community classification systems currently being developed for this region should provide additional important information for interpreting the environment (Atzet and Wheeler 1984, Atzet and McCrimmon 1990).

Forest sites are most often characterized on the basis of average or normal conditions, but managers are challenged to recognize potential fluctuations and weigh their impact on a reforestation program. Atzet (1981) points out that extremes may have a disproportionate effect on reforestation success and species distribution over time. Predicting the occurrence of extreme, irregular events such as prolonged drought, unusually hot or cold temperatures, floods, or wind storms is difficult, but a probabilistic analysis of return period for such events can be useful and may influence site-specific reforestation decisions. For example, irregular, but not uncommon, growing-season frosts on relatively flat, high-elevation sites may necessitate shelterwood management or promotion of frost-resistant species. However, more random events such as the record high temperatures of August 1981 should not be the basis for blanket prescriptions for shelterwood management to minimize seedling mortality from heat. The challenge is to strike a balance between the risk of catastrophic, but unlikely, losses and the broad array of "costs" associated with attempting to protect against them.

Macroenvironment

Macroenvironmental factors—slope, aspect, elevation, soil parent material and other soil characteristics, precipitation, geographic location, and wind patterns—place a site in a particular temperature-moisture-nutrient regime that can influence selection of a reproduction method. For example, regular strong winds and the resulting risk of blowdown of residual overstory trees may preclude shelterwood management of an area, just as regular growing-season frosts may necessitate it if a frost-sensitive species is to be established.

The relationship of a harvest unit to the surrounding landscape can also influence its macroclimate—harvesting activities nearby may lead to changes in the environment of the site being regenerated. A good example is the creation of a frost pocket on gently sloping terrain because of adjacent harvesting that alters air-drainage patterns (Emmingham 1985). Another example is clearcutting on the windward side of a shelterwood stand, an activity that may lead to greater incidence of blowdown of residual overstory trees.

Microenvironment

The microenvironment within which a seedling must become established is a function of four broad interrelated abiotic factors directly affecting survival and growth—light, heat, water, and nutrients—and numerous biotic factors including soil biology, understory vegetation, animal damage, and pathogens and insects (Spomer 1973, Atzet 1981). Seedling microenvironment is influenced by reproduction method—a shelterwood overstory creates a different microenvironment than a clearcut (Childs *et al.* 1985). But beyond this statement, it is difficult to generalize about microenvironmental effects of these two methods on seedling performance because the interacting abiotic and biotic factors can override general attributes of either method.

Abiotic factors

Light.—Solar radiation drives photosynthesis, the energy source for metabolic processes (Spurr and

Barnes 1973). The effects of light on seedling survival and growth depend on its intensity, duration, and quality. A shaded microsite leads to reduced overall seedling shoot and root growth, relatively less root growth than shoot growth, and a tendency toward etiolated stems (Brown 1974, Atzet 1981).

The light intensity required for seedling survival varies by species. White fir, for example, needs less than 2-percent full sunlight, Douglas-fir 2 to 10 percent, and ponderosa pine 20 to 30 percent (Atzet and Waring 1970). Atzet (1981) suggested that shelterwood canopies with 50- to 60-percent crown cover still provide 20-percent full sunlight; therefore, only ponderosa pine may be jeopardized by a dense shelterwood. In fact, partial shade may help reduce stress in seedlings in the first 2 or 3 years before the deleterious effects of too much shade are apparent.

Although minimum light-intensity requirements for survival can be met under fairly dense canopies, the trade-offs in seedling vigor and growth must be recognized, particularly for shade-intolerant species. The less vigorous condition of seedlings grown for prolonged periods in the shade may cause problems for those same trees later on, when they must adjust to exposure after overstory removal, especially on hot, droughty sites.

Growth of established seedlings increases as light intensity increases, generally up to full sunlight. Many publications document the improved growth rate in full sunlight or under less dense shelterwood canopies for commercial tree species in southwest Oregon and northern California (Emmingham and Waring 1973, McDonald 1976a, Williamson and Ruth 1976, Minore *et al.* 1977, Del Rio and Berg 1979, Dunlap and Helms 1983, Strothmann and Roy 1984, Stewart *et al.* 1984, Walstad and Kuch 1987). However, the interaction of light intensity with soil moisture availability is probably a significant consideration, particularly on the hot, dry sites in this area (see later in this chapter, "Water").

Heat.—Whereas meaningful reductions in ambient air temperatures are difficult to document under a shelterwood canopy, reduced temperatures at the air-soil interface and in the soil have been measured. In 1980, Childs *et al.* (1985) compared three clearcuts with three shelterwood stands ranging in overstory basal area from 104 to 161 ft^2/acre and found average soil temperature to a depth of 1 foot beneath the soil surface to be 11°F less in the shelterwoods.

Reduced soil-surface temperatures may be most meaningful for natural regeneration. Experiments have shown that soil surface temperatures of 130 to 150°F can kill seedlings less than 6 weeks old, depending on length of exposure (Silen 1960, Seidel 1986). Such temperatures have been reported regularly on exposed sites in southwest Oregon (Hallin 1968). Shade from overstory trees, as well as other microsite sources such as logs, rocks, or stumps, has improved the survival of germinants where high soil-surface temperatures were encountered (Helgerson *et al.* 1982).

But high temperatures less often injure good-quality planting stock (Halverson and Emmingham 1982, Helgerson *et al.* 1982). In the case of nursery-grown seedlings, 1+0 container stock is probably most susceptible to heat injury. Survival of larger 2+0 bareroot stock was not improved by shade in two studies conducted in northern California and southwest Oregon (Strothmann 1972, Helgerson *et al.* 1982). However, Helgerson and Bunker (1985) suggest the value of artificial shade in survival of lower quality planting stock, stock planted later in the spring than appropriate, and poorly planted stock. Minore (1971) also found that shading improved survival of 3-inch-tall 2+0 bareroot Douglas-fir on the Dead Indian Plateau, where protection from frost is an additional concern.

During August 1981, a prolonged period of high temperatures provided the chance to study the ameliorative effects of a shelterwood canopy on understory environment and seedling survival. Several weeks of unusually hot weather were followed by 4 consecutive days with maximum air temperatures in Medford over 110°F. These conditions apparently are rare, occurring about every 75 years (D.H. McNabb, Oregon State University, personal communication). According to regeneration survey records of the Bureau of Land Management (BLM), survival of operationally planted seedlings in BLM clearcut and shelterwood units that summer was similar (see Table 1). The site conditions of the harvest units surveyed are unknown, but the BLM did control competing vegetation with herbicides in 1981.

Childs and Flint (1987) measured environmental conditions and seedling survival within adjacent clearcut and shelterwood units during 1981 and documented less harsh conditions and better seedling survival under the shelterwood canopy. The first year, 2+0 bareroot Douglas-fir planted in the clearcut suffered 83-percent mortality, whereas few seedlings died before the next growing season under the shelterwood. In the clearcut, many seedlings turned from green to brown within the 4-day heat spell, leading Childs and Flint to hypothesize that unusually high root-zone temperatures there caused almost instantaneous desiccation and death. No heat lesions were observed at the soil surface.

The results of the Childs and Flint (1987) study are difficult to reconcile with those on operational and research sites located in clearcuts in 1981. Though seedling mortality was sometimes significant in other clearcuts, mortality comparable to that observed by Childs and Flint was rare, particularly when competing vegetation was controlled (Helgerson *et al.* 1982). Unfortunately, Childs and Flint provide scant details about the competing vegetation on the two units, except to note that 4- x 4-foot scalps were made by hand at planting. If the seedlings in the clearcut were of low quality, poorly planted, or stressed because of competing vegetation—the scalping treatment used is known to be only marginally effective against the large deerbrush ceanothus (*Ceanothus integerrimus*) scattered on the site—then these results endorse the value of shade in enhancing survival of weakened seedlings. If, however, the seedlings were relatively healthy at the onset of the heat, Childs and Flint's findings should be carefully studied to understand the elements at risk during such temperature extremes.

Whereas a shelterwood canopy may benefit understory seedlings during high temperatures, it may also delay warming of soils in the spring. Problems associated with such suboptimal temperatures may include delayed budburst, decreased root growth, increased root resistance to water uptake, and decreased mycorrhiza activity (Lopushinsky and Kaufmann 1984, Childs 1985), all of which may reduce growth in early summer when soil water is plentiful.

Moreover, whereas daytime air temperatures may not be strongly affected by an overstory canopy, nighttime temperatures are often increased as longwave radiation is retained (Mahrt 1985). Thus, for frost-susceptible areas, a shelterwood overstory may help promote establishment of frost-sensitive species.

Water.—Despite the potentially damaging effects of high or low temperature on young seedlings, most researchers agree that water is the most limiting factor for seedling survival and growth in southwest Oregon (Atzet 1981, Hobbs and Owston 1985). A seedling's water balance is commonly expressed as plant moisture stress or as xylem pressure potential, reflecting a seedling's position in the soil-plant-atmosphere continuum (Greaves *et al.* 1978).

Since southwest Oregon is typically dry and hot during the growing season, the primary source of moisture for tree growth then is water stored in the soil. As long as a soil profile is fully recharged during the winter, the amount of water available to seedlings is a function of soil texture and depth. If soil moisture is not consumed by competing vegetation, the availability and utilization of water are a function of species characteristics, root-system size, and environmental conditions that control water use. To the extent that reproduction methods affect air and soil temperature, wind speed, and amount of available soil water, they also influence seedling moisture relations (Waring and Schlesinger 1985, Radosevich and Osteryoung 1987).

The benefits provided by shelterwood overstory trees may be offset by the amount of water they consume (Hallin 1967). Childs (1985) estimated that an overstory basal area as low as 44 ft^2/acre could account for 20 percent of the seasonal water use on a site, a basal area of 174 ft^2/acre for 50 percent. Field studies in northern California (Dunlap and Helms 1983) and southwest Oregon (S.D. Hobbs, Oregon State University, personal communication) have shown that seedling xylem pressure potential decreases (i.e., water stress increases) as basal area of overstory trees increases, but the trend has not been consistent (Lindquist 1977, Childs and Flint 1987). Site macroenvironment and competing vegetation undoubtedly affect this relationship; therefore, sites should be individually evaluated when the issue of overstory water use may be significant.

Nutrients.—Soil fertility seldom limits reforestation success in southwest Oregon. However, species selection may be influenced on sites with severe deficiencies or unusual chemical balances. For example, knobcone pine (*Pinus attenuata*) may be favored on severely burned, nutrient-poor sites in the Siskiyou Mountains, Jeffrey pine on ultramafic soils. However, even-aged reproduction methods vary little in their effect on site nutrients as long as the site is promptly reforested.

The greatest danger to nutrients, regardless of reproduction method, is through activities associated with slash disposal and site preparation.[3] Prescribed burning is potentially damaging, although current practices have minimized risks to long-term produc-

[3] Throughout, "slash disposal" refers primarily to reducing fire hazard and improving site access for tree planters. "Site preparation," a broader term, refers to improving site access, minimizing competing vegetation, and preparing seedbeds.

tivity (McNabb 1988); historically, shelterwoods were probably burned cooler than clearcuts out of the need to protect residual overstory trees. Very hot burns volatilize nitrogen and may predispose steep slopes to erosion. Machine piling of slash can concentrate nutrient-rich topsoil in windrows, to the detriment of the rest of the site. Herbicides probably pose the least risk to soil fertility because they do not physically disturb the forest floor. Aerial application of chemicals is hindered by a shelterwood canopy, but ground-based applications can be effective with either reproduction method.

Biotic factors

Soil biology.—Foresters are becoming increasingly aware of the significance of various soil organisms to successful reforestation. While much is unknown about the complex belowground ecosystem, most potential impacts seem related to the intensity of practices to prepare seedbeds and control competing vegetation. Fire, in particular, may substantially alter the functioning of the belowground system through impacts on forest floor and soil organic matter, pH, and temperature, and on plant-succession patterns (Borchers and Perry 1990). The most well-documented potential impacts on reforestation are those associated with mycorrhiza.

Amaranthus and Perry (1987) found that some clearcuts not reforested for 8 to 27 years after harvest were deficient in mycorrhizae and that inoculation from nearby vigorous plantations improved seedling survival substantially. They concluded that it may be important to retain a source of mycorrhizal inoculum on sites where reforestation risk is high, particularly on infertile soils and high-elevation, droughty sites. Limiting hot slash burning and retaining overstory trees and other plants that act as alternative mycorrhizal hosts are encouraged (Perry *et al.* 1987). We believe these results are important in explaining why some old clearcuts are now very difficult to regenerate and recommend site-by-site evaluation to determine likelihood of mycorrhiza deficiency.

Methods are being developed to inoculate seedlings with mycorrhizae in the nursery. Where soil biology is an issue, such programs may some day be helpful in establishing seedlings on areas with chronic reforestation problems. We urge caution, however, in implementing recommendations that competing vegetation be promoted on a site as an alternative host for mycorrhizae. Soil-biology considerations must be balanced against the known effects of plant competition for available soil moisture.

Understory vegetation.—The deleterious effects of hardwoods, shrubs, and herbs on conifer seedling survival and growth are well documented (Stewart *et al.* 1984, Tesch and Hobbs 1986, White 1986, Walstad *et al.* 1987). In moisture-limited environments, experts recommend that competing vegetation be minimized for 3 to 5 years after planting (Newton 1981, McDonald and Fiddler 1986).[4] Understory vegetation may also provide habitat for rodents such as mice (*Peromyscus* spp.) and mountain beavers (*Aplodontia rufa*) (Newton 1981), as well as entice other animals like deer (*Odocoileus* spp.), elk (*Cervus* spp.), and pocket gophers (*Thomomys mazama*) into the area in search of high-quality forage (Crouch 1979, Strothmann and Roy 1984). On the other hand, the presence of understory plants may improve conifer seedling survival by reducing extremes of soil surface temperature, preventing erosion on disturbed or unstable sites, enhancing nutrient cycling, improving soil physical and chemical properties through addition of organic matter and nutrients (e.g., nitrogen fixation), offering protection from some browsing animals, and potentially reducing damage from conifer diseases through effects on soil-borne pathogens (Newton 1981, Walstad *et al.* 1987).

Reproduction methods affect understory conditions primarily through the rate at which the soil surface is exposed to full sunlight, triggering rapid germination and growth of competing species. Clearcutting exposes the site immediately, whereas shelterwood management exposes it over several years. Assuming similar site-preparation treatments, revegetation is more rapid in a clearcut than a shelterwood, where the overstory canopy slows understory regrowth.

The consequences of vegetation change during or after the regeneration period depend on the structure and composition of the plant community before entry. With increasing knowledge of the autecology of competitors, it is possible to predict the response of competing vegetation following disturbance (Harrington *et al.* 1984, Tappeiner *et al.* 1984). Certain dense, mature stands may appear competition free, but have high competition potential because of the presence of stored seed or senescent shrub root

[4] Survival and growth of seedlings are enhanced by managing competing vegetation through "plantation maintenance" or "release." Although these two terms are often considered synonymous, plantation maintenance usually refers to treatments that limit regrowth of competitors after site preparation and is aimed at improving survival in the first 5 years. Release treatments typically remove taller shrubs or hardwoods that may be overtopping seedlings and usually are aimed at improving growth.

systems (McDonald and Tappeiner 1986). Gradually opening the canopy during the shelterwood regeneration period may foster development of competing vegetation which must be dealt with once the overstory has been removed. Conversely, maintaining a dense canopy to inhibit competition may retard seedling growth and make logging to remove the overstory more difficult.

Site preparation practices such as using herbicides, fire, or heavy equipment provide flexibility in controlling the seedbed environment during the regeneration period. Although most of these practices may be used in association with shelterwood management, their effectiveness is often reduced and their cost substantially increased over those of clearcutting when overstory trees are present on the site.

Animal damage.—Harvesting and reforestation activities affect habitat, and therefore behavior, of wildlife. For large mammals such as deer and elk, harvesting eliminates hiding cover, but post-harvest development of seral vegetation generally increases food supplies. As such, animals that do not "live" within a harvest unit may be attracted to it as a feeding area, potentially damaging seedlings. For many smaller mammals, such as mountain beaver or pocket gophers, successional changes in vegetation within a harvest unit improve both cover and food supplies, often resulting in a population buildup. Thus, concern about greater presence of animals drawn to a regenerating site is threefold: wildife may (1) consume seed on the forest floor, (2) repeatedly browse seedlings, stunting their growth or inducing poor stem form over long periods, or (3) kill seedlings by browsing or trampling aboveground or damaging roots belowground.

During the regeneration period, clearcutting and shelterwood practices create a different plant-species composition and structure in the understory because of differences in light intensity and soil moisture. Regardless of reproduction method, however, site preparation and release treatments may strongly affect the resulting wildlife habitat. To evaluate the potential for reforestation problems due to a particular animal species, managers should:

- determine how species composition and structure of the existing vegetation will change as a result of management activities. Plant-association guides may be helpful in projecting successional pathways.
- review the historical range, habitat requirements, and life cycle of potential animal pests for clues as to how those species will react to proposed management activities and ensuing changes in vegetation.
- review the silvical characteristics of the tree species being regenerated, the reforestation approach (i.e., natural or artificial regeneration), and the site environment to project the relative risk of animal damage to seedlings.

In many cases such analysis will illustrate that animal damage is not a significant problem or is one that can be solved irrespective of reproduction method. In other situations, selection of reproduction method may influence potential problems. For example, the shelterwood method may be preferred to clearcutting on the relatively gentle slopes of the southwest Oregon Cascades, where pocket gophers and frost interact to create reforestation problems, particularly for frost-sensitive species such as Douglas-fir. Gophers present a major challenge to reforestation success, with poison baiting the most effective tool. A strong relationship is apparent, however, between habitat and gopher populations, which expand rapidly when herbaceous plant communities dominate after harvesting (Crouch 1979). Maintaining fairly dense shelterwood overstories has been effective, in some cases, in preventing the development of the abundant grasses and forbs that benefit the gopher and, at the same time, minimizing frost damage to sensitive species (USDA Forest Service 1979). Where foresters have the flexibility to control herbaceous plants by other methods, such as herbicides, clearcutting and reforestation with less frost-sensitive species have been successful. Further research is necessary to define the relationship of the overstory canopy to understory vegetation for different plant associations, and to unravel the habitat preferences of the gopher.

Pathogens and insects.—Although pathogens and insects present an array of challenges to forest managers over the life of a stand, in few situations do they dictate a choice between the clearcut and shelterwood reproduction methods (Hermann 1978). The one exception to this generalization may be the regeneration of stands infected with dwarf mistletoe (*Arceuthobium* spp.). Because infected overstory trees provide a source of mistletoe inoculum to seedlings, pathologists typically recommend that such sites be clearcut (Hadfield 1986), unless it is possible to select mistletoe-free trees for "leave" trees or to plant nonsusceptible tree species. If mistletoe-infected overstory trees are retained for shade, they should be removed as soon as possible so they cannot infect developing seedlings (Hansen 1978).

The shelterwood method may promote the incidence of certain root rots and stem diseases, such as Indian paint fungus (*Echinodontium tinctorium*) and annosus root disease (*Fomes annosus*), if overstory trees are damaged during the regeneration cut(s). True fir species are particularly susceptible to infection of logging-related wounds. Once present in a stand, some diseases are spread when the infected root systems of the existing overstory contact the roots of newly established seedlings. In such cases, conversion to less susceptible species is often necessary (Hadfield 1986). In susceptible but disease-free stands, the most straightforward approach is clearcutting and planting, but shelterwoods may be used as long as logging practices minimize wounding of leave trees and soil disturbance, and any wounded trees are promptly removed (Aho *et al.* 1983).

In southwest Oregon, the primary insect pests are bark beetles (*Dendroctonus* spp.) and flatheaded borers (*Melanophila drummondi*) (Overhulser 1986). Tree mortality associated with these pests usually develops when trees are wounded during logging, when soil is compacted, or when large amounts of fresh logging slash accumulate. However, in most cases, insects are not a major problem until trees are 6 to 8 inches in diameter at breast height (dbh). Overall, there is little evidence that either clearcutting or shelterwood practices increase the risk of insect attack (Hermann 1978).

Chapter 5: Reforestation Results—The Research Information Base

Clearcutting has been challenged by the public as an inappropriate reproduction method for southwest Oregon. Consequently, much research has been focused on improving reforestation success with this method using both artificial and natural regeneration. Less information is available on the shelterwood method. Publications addressing any form of partial cutting discuss results primarily in the context of natural regeneration; indeed, little has been published about underplanting of shelterwood stands after the regeneration cut.

Most research before 1980 dealt with clearcut and shelterwood units that had received varying amounts of site preparation and, if planted, tended to be stocked with seedlings of unknown origin and quality. Typically, artificial regeneration was not attempted for up to 3 years after harvesting, often after control of the site was lost to competing vegetation. However, recent research often reflects more intensive management and the application of new information, and results generally show substantially improved reforestation of harvested areas. Therefore, when reviewing the information base, we must consider the conditions under which a study was conducted and evaluate how the results might apply to specific current circumstances. The following numbered statements highlight significant elements of the available literature. They report on Douglas-fir, unless otherwise noted.

1. *When artificial regeneration is used and state-of-the-art reforestation practices are followed, clearcut and shelterwood reproduction methods can succeed and produce comparable seedling survival on sites not prone to frost.*

Except where growing-season frost is a problem, there is considerable evidence that prompt reforestation of clearcuts is possible on almost all commercial forest sites in southwest Oregon when good-quality nursery stock is properly planted on well-prepared sites and competing vegetation is controlled. Survival has been good on hot, droughty sites, some of which have been withdrawn from the commercial forest base by the BLM for fear of reforestation failure.

In Adaptive FIR Program research, 21 of 27 clearcut or brushfield reclamation sites had at least one treatment in which survival was 80 percent or better (Tesch *et al.* 1990b; see Table 2). Sites with lower survival typically had problems with competing vegetation or animal damage. For example, Helgerson (1985) found that both Douglas-fir and ponderosa pine survived well after 5 years on the hot, dry, low-elevation Tin Pan Peak site when weeds and rodents were controlled. The lower survival rate observed at the Limp Hog site (Table 2) was associated with severe grass competition.

Side-by-side comparisons of the clearcut and shelterwood methods are rare, especially for planted shelterwoods. However, one major long-term study, underway on steep terrain in southwest Oregon (P.W. Owston and S.D. Hobbs, unpublished data), includes 11 side-by-side pairs of clearcut and shelterwood units across six locations; half of each unit was broadcast burned to compare level of site preparation. The oldest clearcut-shelterwood pair was 8 years of age in 1990. The shelterwoods were designed to leave about 10 overstory trees per acre after the regeneration cut; the overstory has been removed on five of the shelterwood units, typically 4 years after Douglas-fir seedlings were planted. Follow-up vegetation management has been done as needed on all units only to retain the integrity of the experiment.

Results from pairs with the shelterwood overstory removed show that survival was similar for both methods after mortality from overstory removal was accounted for. As many as 30 percent of the Douglas-fir seedlings were damaged but not killed during shelterwood removal, and their recovery may be important to the stocking of the future stand if seedling density is marginal. However, ongoing work shows that Douglas-fir seedlings can heal rapidly (Tesch *et al.* 1990a), and that 50 to 80 percent of damaged Douglas-fir seedlings in one study were classified as crop trees 5 years after logging injury (S.D. Tesch, unpublished data).

Survival in broadcast-burned areas was initially slightly better than that in unburned areas—seedlings benefited from the reduced competition and likely increase in available soil moisture. Early survival was best in burned clearcuts, but was somewhat better beneath the shelterwood canopy than in the clearcuts in unburned areas. These results undoubtedly depend upon the competing vegetation present at the time of harvest. Decisions to burn should be made carefully and include a longer term vegetation-management perspective. In at least one clearcut unit studied, burning stimulated the germination of ceanothus seeds, which has led to intense competition from developing shrubs.

2. *The value of shade for improving the survival of planted seedlings on hot, dry sites is not clear in the literature, and careful site-specific evaluations are recommended.*

Whereas Childs and Flint (1987) reported substantially more seedling mortality in clearcuts than beneath a nearby shelterwood canopy, Helgerson *et al.* (1982) found that shade from a shelterwood canopy did not improve the survival of planted Douglas-fir in southwest Oregon. Seidel and Cochran (1981) generalized that for mixed-conifer forests on the east side of the Oregon Cascades, planted seedlings do not need the protection provided by a shelterwood canopy. Strothmann (1972) also reported that shade did not improve survival of planted seedlings on a south-facing clearcut in northern California. However, numerous studies do report improvements in the survival of shaded, planted seedlings (Minore 1971, Lindquist 1977, Lewis *et al.* 1978, Hobbs *et al.* 1980, Hobbs 1982, Petersen 1982, Helgerson and Bunker 1985). We conclude the following from these various results:

(a) In some studies, statistically significant improvements in survival were obtained with artificial shade, but the survival percentage for both shaded and unshaded seedlings was acceptable. Therefore, the increase in survival due to shading might be of little practical value considering the cost of application.

(b) Shading is of greatest importance to survival when one or more factors in the reforestation process are awry. Examples include use of poor-quality seedlings or seedlings planted late in the spring because of site-access problems (e.g., snow).

(c) Shading may be necessary to ensure survival of frost-sensitive species planted on hot, dry, higher elevation sites also subject to growing-season frosts.

(d) Observations suggest that 1+0 container-grown seedlings may be most sensitive to environmental extremes and benefit most regularly from shade when extremely hot, droughty sites are planted and (or) other problems are anticipated.

(e) Where shade may be beneficial, the trade-off between artificial shading devices and a shelterwood canopy must be considered. Childs *et al.* (1985) point out that shelterwoods ameliorate seasonal soil-temperature conditions and may be more appropriate where cumulative soil heating limits reforestation success. They suggest that shadecards are most useful where heat stress lasts only a few days. However, the analysis is complicated by the fact that shelterwood trees use water, and their presence may make the logistics of vegetation management more difficult; in contrast, shadecards may be positioned after good site preparation and do not hamper follow-up vegetation management.

3. *Natural regeneration can be successful with either clearcut or shelterwood management, but uncontrollable factors often limit prompt stocking.*

Natural regeneration does occur, but it is seldom relied upon on hot, droughty sites or those prone to rapid invasion by competing plants because there are so many variables that cannot be sufficiently controlled to ensure timely, consistent success (Barrett 1979, Seidel and Cochran 1981, Stein 1981, McDonald 1983, Strothmann and Roy 1984). Some initial costs may be reduced when natural regeneration is used, but delays in stand establishment that lead to longer rotations and precommercial thinning resulting from overstocking also are costly.

Successful natural regeneration depends upon the appropriate blend of seed availability, seedbed conditions, and environment. Two of the three can be controlled, at least partially, by choice of reproduction method and site preparation practices. Using Douglas-fir as an example, we know the species is an irregular seed producer; 5- to 7-year cycles between heavy seed crops are not unusual (Fowells 1965). Rodents may consume a significant portion of seed crops, particularly during light seedfall years (Williamson and Twombly 1983). Reducing clearcut opening size and increasing shelterwood seedtree density are two options for taking advantage of light seed crops and minimizing the well-documented lethal effects of hot soil-surface temperatures on germinating seedlings (Silen 1960, Helgerson *et al.* 1982).

Some reforestation failures with natural regeneration in the 1960s have been attributed to lack of adequate seed production for several years after site preparation. After 3 years, planting was attempted, but the site was often completely occupied by competing vegetation by that time (Stein 1986). However, when viewed over somewhat longer periods, natural regeneration can lead to acceptable stocking on lands in southwest Oregon. Between 1973 and 1976, Stein (1981, 1986) surveyed BLM lands harvested between 1956 and 1971 to determine reforestation success of various conifer species. Although many sites had been regarded as regeneration failures within 5 years of harvest, Stein's surveys indicated that most sites were at least 50-percent stocked with seedlings established naturally both before ("advance" regeneration) and after the regeneration cuts. In this case, 50-percent stocking represented a minimum of 125 well-spaced trees per acre, which approaches the lower limits of acceptable stocking levels. Moreover, Bever and Lavender (1955) found that naturally regenerated stands may contain much higher densities than strict stocking interpretations suggest. Stein (1981, 1986) noted that site preparation led to better stocking, and that the rate of seedling establishment slowed markedly once the site was occupied by competing vegetation, frequently leaving a mosaic of stocked and nonstocked areas. He also observed that seedling vigor was often less than desirable, particularly when overstory removal was not prompt. On lower elevation Douglas-fir–ponderosa pine sites, both species were evident in the regeneration of clearcuts and partial cuts. However, on higher elevation mixed-conifer sites, partial cutting often led to changes in species composition; fewer pine and Douglas-fir, and more true fir, were observed (Stein 1986).

4. *When natural regeneration is used with the shelterwood method, the interaction between site preparation and shade is very important.*

Williamson (1973, 1983) predicted that 3 years' seed production should restock an area to about 480 Douglas-fir seedlings per acre on gentle northerly slopes in the mid- to southern Oregon Cascades if an adequate seedbed was prepared. Key to this prediction is that the more mineral soil exposed through site preparation, the less basal area was required to obtain a similar stocking level. Minore *et al.* (1977) also found that scarification under a shelterwood increased stocking of naturally regenerated Douglas-fir seedlings by 25 percent. McDonald (1976a, 1976b, 1983) further observed that site preparation improved survival of ponderosa pine seedlings under shelterwoods in northern California on high-quality sites. Work done in central and eastern Oregon demonstrated that mineral soil seedbeds under shelterwoods improved regeneration of grand fir (Seidel 1979a), red fir (Seidel 1979a), mountain hemlock (Seidel 1979b), and other species growing in mixed-conifer forests (Seidel 1979b).

Seidel (1979a) observed that soil surface temperatures reached 163°F under the canopy of a stand with a basal area of 130 ft^2/acre in eastern Oregon, but duration of such temperatures was less on mineral soil seedbeds. He suggested that a mineral soil seedbed became more critical for sparser overstories. Therefore, it seems that shade and seed alone do not automatically lead to desired levels of natural regeneration. Seedbed conditions are important and cannot be ignored.

Although foresters have no control over the variability of seed production, flexibility to coordinate site preparation with seed availability can enhance natural regeneration as a reforestation tool. Prescribed burning may be difficult to implement in a timely manner, but on flatter terrain, delaying mechanical site preparation until a good seed year may be feasible. On steep terrain, however, exposing mineral soil over extensive areas is very difficult without prescribed burning.

5. *Shelterwood management, with either natural or artificial regeneration, may be necessary to reforest severe frost pockets unless frost-resistant species are available and acceptable to managers.*

When frost-problem areas are identified before harvest, foresters face a choice of two strategies, depending upon the species mix being favored. If regeneration of a frost-sensitive species such as Douglas-fir is a management goal, evidence indicates that between 50 to 60 percent of the overstory canopy cover should be retained (Minore and Carkin 1978), although as little as 20 percent might be sufficient (Williamson 1973). If more frost-resistant species such as lodgepole or ponderosa pine are acceptable, regeneration following clearcutting should not be a problem as long as other important elements of the reforestation process are practiced correctly.

Williamson and Minore (1978) studied shelterwoods and clearcuts located in frost-prone areas on the Dead Indian Plateau. They reported that, in the shelterwoods, canopy cover of 60 percent and residual basal area of 111 to 164 ft^2/acre led to about 90-percent survival of planted Douglas-fir, white fir, and ponderosa pine. In the clearcuts, survival was low for Douglas-fir (16 to 37 percent) and white fir (16 to 46 percent), but better for ponderosa pine (41 to 87 percent).

Local nursery managers are attempting to develop frost-adapted individuals of more sensitive species by selective breeding and by altering the nursery growing regime. Some successes are reported for seedlings encountering light frosts, but innovative nursery practices have not proven adequate to prevent mortality during severe frosts.

6. *The presence of an overstory retards seedling growth.*

Shade may benefit, and in some cases may be essential to, seedling survival, but the overstory does negatively affect seedling growth. When shelterwood overstories are retained to enhance aesthetics, to accommodate timber-sale contract extensions, or to protect seedlings from frost damage, losses in seedling growth—usually directly related to increased overstory density (i.e., percent canopy cover, number of overstory trees per acre, or basal area, varying by species)—are substantial. Generally, the more suppressed seedlings become, the longer they may take to respond to better growing conditions after release (Helms and Standiford 1985; S.D. Tesch, data on file). Shade-intolerant species such as ponderosa pine or Douglas-fir are more negatively affected than are more tolerant species.

McDonald (1976a) compared five reproduction methods (clearcut, seedtree, shelterwood, group selection, and single-tree selection) on a high-quality site in north-central California. After 9 years, height of ponderosa pine, Douglas-fir, white fir, and sugar pine was greatest in the clearcut, with all species except white fir more than twice as tall in the clearcut as under the shelterwood.

Minore *et al.* (1977) found Douglas-fir seedlings under a partially cut stand with 150 ft^2/acre of residual basal area to be 4 to 9 inches shorter after 5 years than those in a nearby clearcut. The greater reduction in height was associated with seedlings growing on unscarified seedbeds.

Gordon (1979) found that growth of red fir seedlings decreased during the first 3 years after harvest as the number of shelterwood overstory trees increased from 10 to 30 trees per acre. After 8 years the average height of seedlings under the less dense shelterwood was nearly twice that of seedlings under the more dense (18 versus 10 and 8 inches, respectively; Laacke and Tomascheski 1986). No clearcut units were available for comparison, but personal observations of the units with 10 trees per acre showed that the tallest trees in open areas between overstory trees were 6 to 8 feet tall.

7. *When the shelterwood method is used, the appropriate number of overstory trees to retain is a function of site, species, condition of overstory trees, and management objectives.*

For both naturally regenerated and planted shelterwoods, greater numbers of overstory trees not only reduce growth of seedlings, but also increase the challenge of removing the canopy safely and cost-effectively after seedlings are established. The prescription must be matched to species needs, stand and site conditions, land management objectives, and perhaps economic or harvesting considerations. For example, more overstory trees may be necessary on frost-prone sites or where shelterwood trees are predisposed to blowdown if too few are left. Fewer shelterwood trees are required to naturally regenerate a gentle, northerly slope. Researchers—noting that foresters generally leave too many overstory trees—recommend that only the minimum number needed to satisfy the demands of a situation be left (Emmingham 1985).

We cannot, with confidence, generalize about how much overstory to leave. In addition to differing species requirements, Williamson (1973) points out that basal area guidelines, in particular, are a function of overstory dbh: more basal area is required for a given level of canopy cover as average overstory-tree diameter increases. For example, to provide 50-percent canopy cover, approximately 110 ft^2/acre of basal area is required for 24-inch-dbh shelterwood trees, but 145 ft^2/acre is required for 48-inch-dbh trees. Tesch (1985) and Emmingham (1985) point out that species crown characteristics also vary and are further influenced by stand-density considerations.

Recommended overstory densities for naturally regenerated shelterwoods representing various species and site conditions are summarized in Table 3. We found no published recommendations for planted shelterwoods. We strongly advise that managers consult the individual publications referenced to fully understand the study parameters before they apply guidelines, particularly when a wide range in basal area is presented.

8. *Success of shelterwood regeneration cannot be judged until after overstory removal is completed.*

In the past, mortality of understory trees during overstory removal has ranged from almost none to virtual obliteration of every seedling. In addition, many seedlings suffer damage that may lead to stocking losses later on. Preliminary results of a study assessing the ability of Douglas-fir seedlings to recover

Table 3. Summary of published recommended shelterwood overstory densities, determined by any of three different measures, for natural regeneration in Oregon and northern California.

Species[1]	Location	Canopy cover (%)	No. of overstory trees/acre	Basal area (ft^2/acre)	Reference
DF	W. slope of Oregon Cascades	50		100-180	Williamson 1973
DF	S. Umpqua River drainage	60		150	Minore *et al.* 1977
DF	Dead Indian Plateau	60			Minore & Carkin 1978
PP	Pacific NW		10-15		Barrett 1979
PP-DF-WF-SP	N. Calif.		12		McDonald 1976a, 1976b
DF-WF-PP	Dead Indian Plateau	60		111-164	Williamson & Minore 1978
GF	Central Oregon			80	Seidel & Cooley 1974
RF	N. Calif.		5-10 old growth		Gordon 1979
RF	E. slope of Cascades			50	Seidel 1979a
Mixed conifer-MH	Central & eastern Oregon			60-80	Seidel & Cochran 1981
MH	Central & eastern Oregon			>100	Seidel & Cooley 1974
Pacific Silver Fir zone (PSF-DF-MH-NF)	Mt. Hood & Willamette National Forests		10-20		Halverson & Emmingham 1982

[1]Species: DF = Douglas-fir; PP = ponderosa pine; WF = white fir; SP = sugar pine; GF = grand fir; RF = red fir; MH = mountain hemlock; PSF = Pacific silver fir *(Abies amabilis)*; NF = noble fir *(Abies procera)*.

from different types of logging damage indicate that many seedlings will recover and may become crop trees, but the healing process can take several years, and some growth may be lost (Tesch *et al.* 1990a). Overall, it may take 5 years after overstory removal for managers to fully assess the success of the operation.

The multitude of interacting factors that determine the level of mortality and damage are discussed in more detail in Chapter 6 . Our point here is that because overstory removal is an integral part of the shelterwood reproduction method, assessing its feasibility before stand entry is as important as assessing strategies for site preparation, stock selection, and vegetation management.

Chapter 6: Operational Considerations for Implementing a Reproduction Method

When comparing operational aspects of the clearcut and shelterwood reproduction methods, forest managers must consider the following five important factors: (1) requirements for project planning and administration, (2) physical feasibility of management activities, (3) potential for damage to seedlings during overstory removal, (4) potential for soil compaction and erosion, and (5) operating costs. The first four are addressed in this chapter, the fifth in Chapter 7.

Requirements for Project Planning and Administration

Good project planning and administration are keys to successful reforestation regardless of the reproduction method. Both may involve similar management activities in approximately the same sequence; however, because of multiple entries, the shelterwood method requires additional preparation to protect overstory trees during the regeneration cut and established seedlings during overstory removal.

Landowners using the clearcut method need plan only a single timber sale to harvest all merchantable timber from a site. Thus, large areas can be harvested and prepared for reforestation with relatively few personnel. In contrast, landowners using the shelterwood method must plan basically the same timber sale two or three times at almost the same cost per entry as for a single clearcut. For government land-management agencies, this process probably includes an environmental assessment, layout of the sale (which demands competent, experienced personnel to protect the residual overstory and established seedlings), timber cruise, contract preparation, cost appraisal, and contract administration. Where there is personnel turnover, each new forester must rethink a predecessor's work. Moreover, planning two or three entries within a 5- to 7-year period, or even longer in extreme cases, also requires good recordkeeping and documentation of actions, a task at which, historically, many landowners have been deficient. For shelterwoods in particular, landowner objectives must be communicated to the logger and ample time allowed for sale administration to ensure that silvicultural and other management objectives are met (Hall 1985).

The desirability of removing the shelterwood overstory when seedlings are a particular size presents an administrative and scheduling problem that may be difficult to overcome, especially for government agencies. The time window when seedlings are at optimum size may be relatively short, but planning and implementing a timber harvesting project are seldom short-term affairs. A project is normally in the administrative unit's timber harvesting plan for up to 5 years before the actual sale of timber takes place. Logging on a particular project is usually allowed any time during the active period of the sale contract, which may be several years long. Timing of actual harvest may be related to market conditions, with harvest delayed if demand for timber falters or accelerated if timber is in short supply. Where the shelterwood method is used, forest managers should plan for careful monitoring of seedling growth, try to be as flexible as possible with the timing of timber sales, and make reasonable contractual requirements for purchasers to harvest units slated for overstory removal by specified dates during the sale period.

It may be helpful from a silvicultural and an administrative viewpoint to sell the entire timber volume in a shelterwood as a single project. Thus, the purchaser would harvest the volume designated for removal in the regeneration cut, wait until seedlings were established and had reached a certain size, then return to remove the overstory, all as part of the same timber sale. To our knowledge, this approach has not been attempted in southwest Oregon, but longer term land-stewardship contracts have been used successfully for other management activities such as tree planting and follow-up plantation maintenance (Porterie *et al.* 1986).

The inherent flexibility associated with the two reproduction methods must be considered in planning. The shelterwood method is flexible in that seed can continue to be produced and the site protected as long as overstory trees are retained and kept healthy. But an overstory damaged during the regeneration cut or site preparation, or by a catastrophic event such as high winds, may provide inadequate cover—in which case the "shelterwood" will not be present as planned. Conversely, if additional overstory trees are left in anticipation of losses and all survive, the "excess" timber to be harvested during overstory removal will increase logging difficulty and may cause excessive damage to established seedlings. Clearcutting, somewhat less flexible than the shelterwood method, requires careful analysis and planning before implementation because removing the entire canopy at once is an irreversible act. Some operational flexibility may exist (e.g., to reburn or respray a site), but certain problems may be unexpected and difficult to address (e.g., a suddenly apparent frost pocket).

Physical Feasibility of Management Activities

The physical feasibility of performing a planned operation is mainly limited by topography—that is, slope steepness. As slope increases beyond about 35 percent, tractors usually can no longer be used for timber harvesting and site preparation. Thus, for both clearcut and shelterwood management on steeper terrain, cable or aerial logging systems must be used for harvesting, with mechanized site preparation no longer a practical alternative. The differences in feasibility between the two reproduction methods, for a given terrain steepness, are introduced by the need for protecting overstory trees and established seedlings with the shelterwood method.

Reviewing the literature, we found little research comparing the logging aspects of these reproduction methods. The following numbered statements highlight some of the most important practical knowledge on physical feasibility, gained from personal observations and from discussions with others who have dealt with this issue over many years.

Logging

1. *Shelterwood management is most feasible on slopes up to about 35 percent.*

Trees can be harvested with greater control over the forces of gravity on gentler, tractor-loggable terrain (slopes up to about 35 percent) than on steeper terrain. This means that special measures to protect shelterwood overstory trees and established seedlings—such as stage felling and skidding, directional felling (Hunt and Henley 1981), and designated skidtrails (Garland 1983)—can be used to great advantage. Though some of these same measures can be employed on steeper slopes, they are much more costly and do not provide comparably good results.

2. *As slopes increase beyond 35 percent, shelterwood management is more challenging because log control during felling, bucking, and yarding is increasingly difficult.*

Felled trees and bucked logs move downhill under the force of gravity on steeper slopes. Cable yarders have inherently less log control during yarding than tractors, and even when skyline corridors are located perpendicular to the contour of the terrain, more area generally is disturbed and more of the overstory or understory damaged because of limited log control during lateral yarding.

3. *On slopes greater than about 65 percent, controlling log movement during felling and yarding is extremely difficult, and a decision to use shelterwood management must be made cautiously.*

No matter which logging techniques are used, there is a physical limit to controlling log movement on slopes in excess of about 65 percent (Lindsay 1985). On such steep terrain, there are fewer practical ways to restrict log movement during felling or yarding, although cable-assisted felling may help hold logs in place after felling and bucking during overstory removal.

4. *Downhill skyline logging in shelterwood management should be avoided.*

For the reasons already stated—lack of log control—downhill skyline logging in shelterwoods usually does not produce good results. Logs tend to roll ahead of the skyline carriage on slopes over 65 percent, and to the side of the skyline corridor, widening corridors and damaging overstory trees and established seedlings. The exception might be when there is enough skyline deflection and carriage clearance to achieve total log suspension during yarding, but lateral yarding damage can still be substantial.

5. *High-lead yarding, under normal circumstances a relatively inexpensive cable system, can be used in clearcutting but not with the shelterwood method.*

High-lead systems have no lateral yarding capabilities and provide little vertical lift to logs being yarded. Therefore, typically more costly skyline or helicopter systems must be used on steep terrain for shelterwood management. Where site preparation tools are limited, high-lead yarding can provide some scarification and improved access to planting sites.

6. *Extremely long skyline spans should be avoided in shelterwood management.*

Long skyline spans (in excess of 2000 feet) may cause more damage to overstory trees and established seedlings than short spans, especially if the skyline is suspended below the tops of residual trees (Fieber *et al.* 1982). Yarding low volumes per unit area over such long distances with cable systems may also prove to be uneconomical from a yarding-production basis (Sessions 1978). Where shelterwood management is planned for areas that would require long yarding distances, helicopters may be more economical than cable systems, and should damage seedlings less during overstory removal. Recent timber sales in Oregon and Washington that were originally planned for long-span skylines have been logged by helicopter without any adjustment in cost appraisals, indicating that helicopters are a reasonably economical substitute for skyline logging in some situations.

7. *Helicopter yarding, generally more expensive than either tractor or skyline yarding, may be one way to help reduce seedling damage on steep terrain.*

In their Grub Gulch study, Tesch *et al.* (1986b) found that about half of total seedling damage during overstory removal with a skyline system could be attributed to felling, and half to yarding. Trees felled in cable operations must be "in lead" with the yarding direction; this facilitates yarding, but may be to the detriment of the residual stand. In contrast, trees felled in helicopter operations do not have to be in any particular lead, and timber cutters can be more conscious of saving overstory trees or established seedlings.

With helicopter yarding, logs are typically lifted vertically from their resting position after felling, and then flown suspended beneath the aircraft to a landing site without ever touching the ground. Therefore, helicopter yarding might reduce seedling damage by as much as 50 percent, the amount associated with cable yarding in the Grub Gulch study (Tesch *et al.* 1986b). Although no studies have tested this hypothesis, helicopters have been used for overstory removal with generally good results.

Site preparation and plantation maintenance

1. *Mechanized site preparation is currently a viable option only on slopes less than about 35 percent.*

There have been attempts to prepare steep sites for reforestation with various mechanical implements attached to skyline cables, but they have been largely unsuccessful and very expensive (Steffan 1982). Some new machines are being developed and have been tested on slopes up to 60 percent; they appear to offer potential but are not currently used on a large scale. This leaves burning and herbicides as primary tools for site preparation on steep slopes.

Shelterwood stands can be underburned after the first harvesting entry. But underburning shelterwoods is more difficult and typically more expensive than broadcast burning clearcuts. Underburning is particularly difficult and risky if less fire-tolerant true fir species are present in the shelterwood overstory. Hand piling and burning also are possible, but costs are greater than for broadcast burning.

2. *Aerial spraying of herbicides is generally not practical in shelterwood stands, regardless of slope steepness.*

Herbicides applied from aircraft are largely intercepted by overstory trees and do not reach their intended target, competing ground vegetation. Using backpack-mounted sprayers under such circumstances is likely to be successful, but more expensive than aerial spraying; on gentle terrain, tractor-mounted sprayers can apply herbicides at more moderate costs. Skinner (1983) found that tractor-mounted sprayers could be used almost as cheaply as helicopters; however, his sample size was very small, and the conclusions have been challenged.

Potential for Damage to Seedlings during Overstory Removal

A number of logging techniques can help minimize seedling damage during shelterwood overstory removal with both tractor and cable logging systems (Mann 1985). However, each of these techniques represents an additional logging cost over what is normally required with clearcutting. With the shelterwood method, good logging practices by skillful timber fallers and yarding crews can certainly result in acceptably stocked stands of healthy conifer seedlings, provided that stocking is more than adequate before overstory removal. However, even under the best circumstances, some seedlings will be killed. A goal of overstory logging may be to minimize the impact of that mortality on the overall distribution of seedlings across the harvest unit.

The percentage of seedlings damaged during harvesting ranges widely—from less than 10 percent to nearly 100 percent. Factors observed to contribute to the operational success or failure of overstory removal include seedling size at time of logging, layout of the logging pattern in relation to the terrain (Tesch *et al.* 1986a, 1986b), overstory gross volume, and conduct of the logging operation itself (Aho *et al.* 1983). Research that will integrate these factors and aid foresters in predicting the likely outcome of an overstory-removal operation is underway (Mann and Tesch 1985). Sampling 36 units in which the overstory had been removed by skyline logging, Mann (unpublished data) has found that the percentage of seedlings damaged can be predicted as a function of gross overstory volume per acre removed, initial seedling height, and initial seedling density (total number of stems per acre). His equation explained 78 percent of the variation in seedling damage. Damage in the sample varied from 8 to 81 percent; gross overstory volume ranged from about 6 to 35 thousand bd ft/acre, initial seedling height from 10 to 100 inches, and initial seedling density from 250 to 3100 stems per acre.

Further information on damage to seedlings due to overstory removal is becoming available from the southwest Oregon clearcut-shelterwood comparison study mentioned in Chapter 5 (P.W. Owston and S. Hobbs, unpublished data). Mortality from overstory removal completed on five shelterwood units has ranged from 4 to 11 percent of the original number of seedlings planted. Damaged live seedlings accounted for an additional 14 to 29 percent of seedlings planted (P.W. Owston, Pacific Northwest Research Station, Corvallis, personal communication). These percentages would be even higher if calculated on the basis of numbers of surviving seedlings at the time of overstory removal, a more traditional method of characterizing logging damage.

Several studies have generally concluded that smaller seedlings survive logging better than larger ones (Gaas 1974, Benson and Gonsior 1981, Tesch *et al.* 1986b). However, there is evidence that very small seedlings also are at risk, and that the overstory should not be removed too soon. In an early Adaptive FIR case study (Tesch *et al.* 1986b), planted seedlings in the 24- to 40-inch height class survived the impacts of overstory removal, especially yarding, the best (Figure 2). Those taller than 40 inches apparently were too rigid to withstand logging damage, and defect-creating injuries and seedling mortality increased. Yet very small seedlings (i.e., those shorter than about 24 inches) apparently were not yet firmly rooted and were susceptible to being dislodged. We also have observed seedlings less than 24 inches tall that showed no evidence of damage immediately after overstory removal, but that later died. It is impossible to attribute such mortality solely to logging impacts; however, there is evidence from an ongoing study that stems and roots of small, flexible seedlings receive "invisible" damage, as logs roll over them, which later proves fatal (Tesch *et al.* 1990a). Thus, though seedlings not killed during overstory removal seem able to recover from a variety of logging injuries (Tesch *et al.* 1985, Tesch *et al.* 1990a), those less than 24 inches tall have fared the worst, apparently because of limited photosynthetic capacity and energy reserves. Overall, Douglas-fir seedlings in the 24- to 40-inch height class seem flexible enough to withstand some degree of physical impact during overstory removal, but are well enough established to survive and fully recover from modest amounts of damage without major defects.

These findings somewhat contradict recommendations by Jaszkowski (1975), who suggested overstory trees be removed before seedlings are taller than 18 inches. For discussions about small seedlings in particular, it may be important to clarify whether the seedlings are natural or planted. Some evidence indicates that naturally established seedlings, especially ponderosa pine (McDonald 1969), are adequately rooted by age 2 years although less than 2 feet tall. It is unclear if Jaszkowski's (1975) recommendations are based on natural or planted seedlings; we have studied mostly planted seedlings. It is very likely that natu-

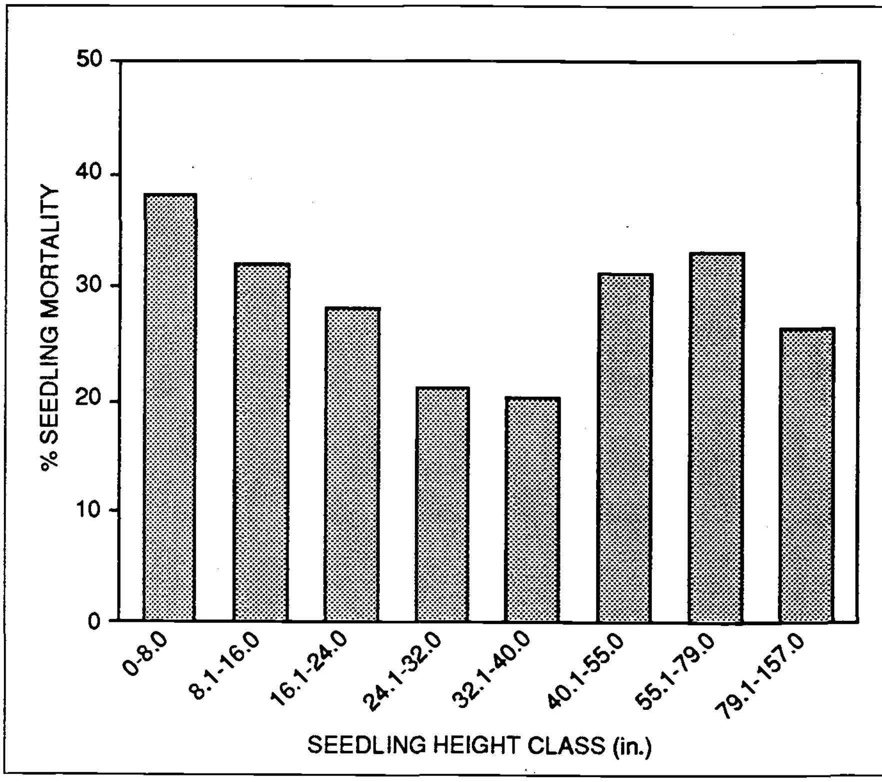

Figure 2. Seedling mortality caused by skyline yarding logs uphill during shelterwood overstory removal on the Grub Gulch timber sale (adapted from Tesch et al. *1986b). Height classes have been converted from 20-cm classes and are rounded to the nearest inch.*

ral seedlings of most species establish a deeper root system quickly, but their small crown may still limit their ability to survive sudden exposure or recover from wounds, especially on severe sites.

Potential for Soil Compaction and Erosion

The list of possible adverse environmental effects from skidding and yarding operations is long and varied. However, concerns for the long-term lowering of site quality from using heavy equipment in harvesting and site preparation are generally soil related—in southwest Oregon, they are principally related to soil compaction and erosion (Froehlich and McNabb 1984).

Potential for site damage is more a function of logging plan and equipment, topography, and inherent soil properties than of reproduction method. On flatter terrain, a major concern is the percentage of area vulnerable to soil compaction from machines skidding logs and preparing sites. The use of designated skidtrails can reduce impacts on soils for both reproduction methods by limiting machine travel within the area and requiring logs to be winched into skidtrails (Froehlich 1977, Bradshaw 1979, Froehlich *et al.* 1981), often without reducing logging productivity (Tesch and Lysne 1983, 1986, Brown and Perry 1984, Sessions and Mann 1985).

On steeper terrain, soil erosion becomes a greater concern than soil compaction, but again its potential for damage is related more to inherent soil properties, logging plan, and yarding equipment than to reproduction method. For susceptible soils, erosion is a function of precipitation regime, terrain, soil compaction, and amount of bare ground exposed by logging and site preparation. In general, cable (Aulerich *et al.* 1974) and helicopter yarding systems cause very little soil compaction. High-lead yarding may disturb much of the soil surface, skyline operations relatively little. Except that high-lead logging is seldom feasible in a shelterwood, both reproduction methods offer generally similar opportunities for preventing soil erosion. Multiple entries associated with the shelterwood method redisturb some parts of the site each time, and skyline corridors may have to be placed closer together because lateral yarding capabilities are more limited, given the need to protect residual overstory trees and established seedlings.

Regardless of the reproduction method, strategies to address soil compaction and erosion involve more than just logging. An efficient solution requires that forest managers consider other mechanized activities, particularly slash disposal and site preparation. Otherwise, the anticipated benefits from using designated skidtrails in yarding may be negated by indiscriminate use of crawler tractors in other operations.

Chapter 7: Economic Considerations for Selecting a Reproduction Method

In this chapter, we compare the types of costs associated with the clearcut and shelterwood reproduction methods to demonstrate the impact of the relative cost differences on long-term investment decisions. Through these comparisons, managers should be better informed of the economic trade-offs involved in selecting one method over the other. Economic analyses of clearcut and shelterwood methods require information on yields, stand cultural costs, stumpage values, and precise silvicultural prescriptions for both methods applied to the same units of ground (Brodie 1985).

We recognize that, in many cases, economic considerations are not a criterion for selecting reproduction method. We are not necessarily recommending that they should be. Obviously, management objectives vary not only by type of ownership but also by site, and treatment strategies and their costs are site specific. For this discussion, we assume that both reproduction methods are ecologically and physically feasible on a particular site, that timber production is the management objective, and that artificial regeneration by planting seedlings is the reforestation approach (as previously mentioned, most shelterwoods in southwest Oregon where Douglas-fir regeneration is favored are planted).

Yields

Differences in yields between the clearcut and shelterwood reproduction methods are typically a function of three factors: (1) potential for prompt reforestation, (2) effect of residual overstory on seedling growth, and (3) delay in overstory removal.

Except for extreme sites, the potential for prompt reforestation should differ little between the two methods when artificial regeneration is used. But, as previously noted, site preparation and plantation maintenance are usually prerequisites for both (Shepard and Larsen 1985).

Effect of the residual overstory on growth of understory conifer seedlings is probably minor when the overstory is removed less than 5 years after seedlings are planted. However, this factor needs greater attention when overstories are retained for longer periods or entire rotations in frost pockets or other sensitive areas.

Indeed, delay in harvesting the residual overstory is usually the shelterwood characteristic that most affects yield. The present value of that delayed harvest is typically less than it would be if the residual trees were harvested today, except when the residual trees are growing fast enough, considering mortality and losses to decay, that their merchantable value is increasing at a rate greater than the interest rate used in the economic analysis (Tedder 1981). Such positive net merchantable growth rates are least likely in old-growth stands where mortality and decay are great.

Costs

The main costs associated with reforestation are those for (1) logging, (2) slash disposal and site preparation, (3) vegetation management for plantation maintenance, and (4) seedlings and planting (assuming artificial regeneration). Costs associated with factors (1), (2), and (3), which tend to differ, are discussed next in this chapter; those associated with (4) do not tend to differ and therefore are not discussed.

Logging

Logging costs are commonly regarded as the key difference between the clearcut and shelterwood reproduction methods, particularly on steep sites where cable or aerial yarding is used. With clearcutting, the high cost of using heavy equipment for harvesting is minimized. Logging equipment works the site less frequently during the rotation than in a shelterwood, and, with no overstory trees and established seedlings to protect, harvesting operations can more often be designed to help prepare sites for planting as well (Watson *et al.* 1984).

Shelterwood logging costs are always greater than clearcutting costs because logging equipment must be moved to and from the site ("move-in" and "move-out" costs) at least two separate times to harvest the same volume of timber (Kramer and Conan 1985). This means that move-in and move-out costs are doubled on a per-unit-volume-of-timber-harvested basis. If total timber-sale volume or volume per unit area is small, the additional cost per thousand board feet for equipment can be quite high. For instance, if a timber sale had a total equipment-movement cost of $20,000 and a total volume of 1.5 million bd ft, the cost for this part of the operation would be $13/thousand bd ft. If, however, the sale had a total volume of 5 million bd ft, the equipment-movement cost would only be $4/thousand bd ft. If volumes per acre are low, logging equipment will have to move more often, increasing nonproductive time.

Protecting overstory trees during the initial shelterwood cut commonly requires more sophisticated harvesting equipment (most notably a skyline system with lateral yarding capabilities), more administrative control, and often a more complex logging plan necessitating additional landings and the respooling of lines at each yarder setting to avoid damage to standing trees. Timber-felling and yarding productivity during such a harvest is reduced from that of clearcutting because standing trees are obstacles for all logging activities. They are also safety hazards for loggers because limbs may be knocked out of them; this is particularly true for skyline logging systems when the suspended cables often brush against tree crowns. The degree to which productivity is reduced is extremely variable, but could be 50 percent or more (Lindsay 1985).

During overstory removal, special logging requirements to minimize damage to seedlings also reduce operational productivity and therefore increase per-unit costs. Such requirements might include directional timber felling to specified patterns (Hunt and Henley 1981), stage felling and yarding (J.W. Mann, in preparation), predesignated skidtrails or skyline corridors, and limits on skidtrail and corridor spacing as well as on log length. In a three-stage shelterwood, these factors are complicated by an additional entry into the stand.

A fairly simple example provided by the BLM's Medford District illustrates the relative costs of harvesting a 28-acre unit on steep terrain with both reproduction methods (Brush 1984). The example unit contained 40 thousand bd ft/acre of overstory trees, ranging in dbh from 28 to 60 inches (average dbh, 29 inches). Productivity and costs for a Madill 071 skyline yarder rigged in a high-lead configuration for clearcutting were compared with those for the same yarder rigged in a skyline configuration for a two-entry shelterwood. Analyses indicated 5 landings were necessary for the clearcut alternative and 11 for the shelterwood alternative, with costs for rigging each landing assumed to be equal for the clearcut and the first shelterwood entry. Yarding and loading costs are primarily a function of tree size and volume removed during each entry. In the clearcut, all 40 thousand bd ft/acre were removed (average diameter of merchantable logs, 29 inches). In the shelterwood, 32 thousand bd ft/acre were removed at first entry (average log diameter, 35+ inches), 8 thousand bd ft/acre at second entry (average log diameter, 25 inches).

Present-value analysis for this example case (see box below) shows that yarding and loading costs per

Present-value Cost Analysis

Clearcut alternative

- One entry only: removes 40 M bd ft/acre, average log diameter is 29 inches.

  Yarding and loading costs: $29.75/M bd ft x 40 M bd ft/acre = $1,190/acre

  Yarder "move-in and move-out" and landing rigging costs:

  $\frac{\$495 \text{ move in/out} + 5\ (\$272/\text{landing})}{28 \text{ acres}}$ = $66/acre

  Total present value of costs (yard, move equipment, rig) = **$1,256/acre**

Shelterwood alternative

- First entry: removes 32 M bd ft/acre, average log diameter is 35+ inches.

  Yarding and loading costs: $32.05/M bd ft x 32 M bd ft/acre = $1,026/acre

  Yarder "move-in and move-out" and landing rigging costs:

  $\frac{\$495 \text{ move in/out} + 11\ (\$272/\text{landing})}{28 \text{ acres}}$ = $125/acre

  Present value of costs (first entry: yard, move equipment, rig) = **$1,151/acre**

- Second entry: removes 8 M bd ft/acre 5 years after first entry, average log diameter is 25 inches. (Costs discounted to present at 7.875%.)

  Yarding and loading costs: $35.80/M bd ft x 8 M bd ft/acre = $ 282/acre

  Yarder "move-in and move-out" and landing rigging costs:

  $\frac{\$339.25 \text{ move in/out} + 11\ (\$186.42/\text{landing})}{28 \text{ acres}}$ = $85/acre

  Present value (second entry, year 5: yard, move equipment, rig) = **$367/acre**

Total present value of costs (first and second entries: yard, move equipment, rig) **$1,518/acre** unit volume for the clearcut were less than those for the first shelterwood entry, despite the smaller average log diameter in the clearcut, because of higher costs associated with protecting residual overstory trees in the shelterwood. Despite discounting to the present, yarding and loading costs were still substantially higher per thousand board feet for the second shelterwood entry because of the decrease in log diameter (to 25 inches) and in volume yarded (to 8 thousand bd ft). In this present-value analysis, it cost $262/acre more—an increase of about 21 percent—to use the shelterwood than the clearcut alternative.

A more elaborate example was prepared by Kramer and Conan (1985) using data from the Tiller Ranger District, Umpqua National Forest. They appraised costs for harvesting two 30-acre units, one on a 20-percent slope for tractor logging (Caterpillar D-7) and another on a 45-percent slope for skyline logging (Madill 071 yarder). Analyses were based on gross volumes of 42 thousand bd ft/acre (35 thousand bd ft/acre net). Eight cost centers were evaluated—(1) felling and bucking, (2) skidding, (3) loading, (4) equipment depreciation, (5) slash disposal, (6) erosion control, (7) temporary roads, if needed, and (8) regeneration (Table 4). In this analysis, total costs for the shelterwood method were 39 percent higher ($1,249/acre) than those for the clearcut method on steep terrain and 13 percent higher ($363/acre) on the flatter, tractor-loggable terrain.

Table 4. Cost-center comparison for the clearcut (CC) and shelterwood (SW) reproduction methods with two harvesting techniques (Kramer and Conan 1985).

Cost center, by harvesting technique	Shelterwood[1]	Clearcut	Percent cost difference, SW over CC
	--- ($/thousand bd ft) ---		
Skyline logging			
Felling & bucking	13	13	0
Skidding	50	30	+66
Loading	13	8	+38
Depreciation	10	8	+35
Slash	21	17	+24
Erosion	0	0	N/A
Temporary roads	0	0	N/A
Regeneration	19	15	+23
Cost summary	126	91	+39
Tractor logging			
Felling & bucking	12	12	+0
Skidding	16	15	+7
Loading	8	8	0
Depreciation	2	2	0
Slash	19	16	+16
Erosion	1	1	+92
Temporary roads	1	1	+25
Regeneration	29	23	+25
Cost summary	88	78	+13

[1]Each value is the weighted averages of two shelterwood entries.

Slash disposal and site preparation

Slash disposal and site preparation often go hand in hand. It may be important to reduce fire danger by disposing of slash, but it is equally important to improve access to the site for reforestation and stand cultural activities and to control competing vegetation while seedlings become established.

On steep terrain, the primary tool available for slash disposal and site preparation is burning. Unmerchantable material can sometimes be yarded ("YUM" yarding) to reduce fire hazard and clear areas for planting trees, but using machines for site preparation is generally impractical. With the shelterwood method, practices are complicated by the presence of overstory trees during the regeneration cut and are typically more expensive than with clearcutting. On more gently sloping terrain, broadcast burning, tractor piling and burning, and YUM yarding are primary tools for managing slash, but discing, plowing and ripping can also be used for preparing sites. Costs of such machine activities on gentler terrain should vary minimally for the clearcut and shelterwood methods.

In the past, prescribed burning beneath shelterwood overstories (underburning) often increased costs by $100 or more per acre over those of broadcast burning clearcuts (Shepard and Larsen 1985). Because shelterwood units were underburned slowly by igniting narrow strips of ground at a time, personnel costs were high. Often, such units were burned at night when personnel must be paid overtime. Broadcast burns in clearcuts were cheaper because large areas were ignited rapidly, reducing personnel costs. However, in recent years costs for burning on the BLM's Medford District are estimated to be only slightly higher for underburning than for broadcast burning (Table 5). The typical shelterwood overstory now contains fewer trees per acre to protect, and the units are being burned under somewhat cooler and moister conditions; therefore, areas can be ignited more quickly because risk of losing control of fires is less,

Table 5. Typical costs (1990 estimates unless otherwise noted) of slash disposal, site preparation, and plantation maintenance on clearcuts and shelterwoods for public agencies in southwest Oregon and northern California.

Treatment, by agency	Cost ($/acre)
Medford District, BLM	
Broadcast burning, medium fuels	175 - 209
Underburning, medium fuels	195 - 231
Herbicide[1]	
Aerial	42
Backpack	106
Rogue River National Forest, Forest Service	
Broadcast burning	300
Underburning	350
Hand piling (10-19 ton/acre)	450
Burning piles	30
Region 5, Forest Service[2]	
Broadcast burning	200 - 400
Underburning	—[3]
Hand piling	30 - 685
Flat ground	200
Steep ground	400
Burning piles	60
Herbicides	
Aerial	75
Ground machine[4]	70
Backpack	140

[1]1982 costs; last year herbicide was applied before injunction.

[2]Skinner (1983), USDA Forest Service (1988).

[3]Not listed separately.

[4]Costs from Skinner (1983) may be unrealistically low for a large-scale, ground-based application program today.

and a smaller fire-tending crew is required. Costs for burning clearcuts are increasing as air-quality regulations and mop-up requirements slow fire ignition and require more labor.

Hand piling and burning may be the only option available to dispose of slash after overstory removal, with costs ranging from $90 to as much as $745/acre (Table 5). It should be possible to minimize this cost by using the previously discussed techniques to dispose of as much slash as possible after the regeneration cut and by selecting residual overstory trees with minimum defect. However, some hand piling after overstory removal may be beneficial to uncover seedlings buried in slash.

Vegetation management for plantation maintenance

Vegetation-management methods for ensuring seedling survival during the first 5 years or so after planting are about as effective and expensive on clearcut- as on shelterwood-regenerated areas, with the exception of aerially applied herbicides (Shepard and Larsen 1985). The shelterwood canopy creates a higher risk to the helicopter pilot and a greater likelihood of poor herbicide coverage near overstory trees, so backpack sprayers are commonly used to apply herbicides on steep terrain, usually at substantially higher costs (1.5 to more than 3 times greater for backpack than aerial; see Table 5). On flatter terrain, tractor-based sprayers may be used to apply herbicides under shelterwood canopies at costs intermediate between those of aerial and backpack applications.

The long-term impact of cost differences for vegetation management in clearcuts and shelterwoods during the regeneration period is likely greater than that associated with cost differences for logging, slash disposal, and site preparation. Such costs are regarded as expenses of harvesting and reduce stumpage value, whereas treatments to ensure seedling survival and growth must be amortized over the life of the stand; thus, even relatively small cost differences mount quickly over a rotation. Although future harvesting costs have little impact when discounted to the present, the net present value of an existing stand, as influenced by today's harvesting costs (which require no discounting), is often the key factor in determining the outcome of an economic analysis.

Cash-flow Analyses of Clearcut-Shelterwood Alternatives

Silvicultural prescriptions that compare clearcut and shelterwood alternatives were not readily available. The three prescriptions presented here, which reflect somewhat different sets of assumptions, are intended to demonstrate the impact of the relative costs associated with the clearcut and shelterwood reproduction methods over entire rotations. All three prescriptions, prepared by USDA Forest Service personnel in southwest Oregon, represent different stand, site, and treatment conditions. Interest and inflation rates were set by the prescription authors. In the summaries of the cash-flow analyses (Tables 6-8), net present value (NPV) represents all costs and revenues associated with an existing stand or other nonrepeating rotations discounted to the present. Soil expectation value (SEV) represents the NPV of an infinite series of similar future rotations starting from bare ground. Net present amount (NPA)—the sum of NPV and SEV—enables management alternatives with varying rotation lengths to be compared on an equal time basis.

The three prescriptions serve only as examples and are not recommendations. Obviously, many factors that would affect the absolute outcome could change with each regime.

Example 1—Onion Bowl timber sale

This prescription was written for a stand within the Galice Ranger District, Siskiyou National Forest (Craig 1980). The stand, primarily old-growth Douglas-fir, was located on a 50-percent slope that necessitated cable logging.

Cash-flow analysis for this timber sale uses an interest rate of 5 percent and bases its costs on District experience. The analysis assumes no increase in the value of the residual shelterwood trees for the 6 years they are left standing. Timber values for future stands are assumed to increase at the rate of 2 percent per year for the next 60 years.

Analysis (Table 6) shows that the main differences between the clearcut and shelterwood alternatives are (1) the substantially higher appraised timber stumpage values for the clearcut than shelterwood alternative, which reflect the increased cable-logging costs for the latter, (2) the greater cost of underburning in the shelterwood relative to broadcast burning in the clearcut, and (3) the additional costs of hand piling and replanting after overstory removal in the shelterwood. If economics were the only decision criterion, clearcutting would be the preferred alternative: shelterwood management produces less income in both the short- and long-term scenarios (Table 6).

Table 6. Cash-flow analysis for the Onion Bowl timber sale (Craig 1980).

Year	Operation[1]	Cash flow/ acre ($)	Year	Operation[1]	Cash flow/ acre($)
	Clearcut alternative			**Shelterwood alternative**	
0	*Clearcut (36 M bd ft @$370/M bd ft)	+13,320	0	*Harvest shelterwood (20 M bd ft @$296/M bd ft)	+5,920
	*Broadcast burn	- 155		*Underburn	- 355
1	Plant with animal protection	- 330	1	Plant with animal protection	- 330
6	Release (aerial spray)	- 55	6	*Remove overstory (16 M bd ft @$296/M bd ft)	+4,736
16	Precommercially thin	- 148		*Treat slash (hand pile)	- 420
	Treat slash	- 61	7	Replant 15%	- 50
45	Thin (2 M bd ft @$542/M bd ft)	+1,084	8	Release (aerial spray)	- 55
	Treat slash	- 102	16	Precommercially thin	- 148
60	Thin (5 M bd ft @$728/M bd ft)	+3,640		Treat slash	- 61
	Treat slash	- 204	45	Thin (2 M bd ft @$542/M bd ft)	+1,084
75	Thin (5 M bd ft @$910/M bd ft)	+4,550		Treat slash	- 102
	Treat slash	- 204	60	Thin (5 M bd ft @$728/M bd ft)	+3,640
90	Clearcut (33 M bd ft @$1,214/M bd ft)	40,062		Treat slash	- 204
	Broadcast burn	- 155	75	Thin (5 M bd ft @$910/M bd ft)	+4,550
				Treat slash	- 204
	NPV (existing stand)	13,165	90	Harvest shelterwood (20 M bd ft @$971/M bd ft)	+19,420
	SEV (future rotations)	+477		Underburn	- 355
	NPA	13,642	96	Remove overstory (13 M bd ft @$971/M bd ft)	+12,623
				Treat slash	- 420
				NPV (existing stand)	8,786
				SEV (future rotations)	+288
				NPA	9,074

[1]M bd ft = thousand board feet for Tables 6, 7, and 8.
*Asterisked items not included in calculation of SEV.

Example 2—Center Ridge timber sale

This prescription was written for a stand within the Ashland Ranger District, Rogue River National Forest (Teubner 1983). Douglas-fir and white fir dominated the 40-percent slope. The stand had been cable logged in 1982 as the preparatory cut of a three-stage shelterwood; a relatively small amount of timber, primarily low-value white fir, was removed at that time. The resulting stand contained a dense overstory and had a severe dwarf-mistletoe infection.

Cash-flow analysis for this timber sale uses an interest rate of 4 percent and bases its costs on District experience. The analysis assumes future costs and returns are based on current values. Future stand value per cunit is assumed to increase with increasing average diameter of trees to be harvested.

Analysis (Table 7) shows that the main differences between the clearcut and shelterwood alternatives are as follows: (1) most of the valuable timber in the shelterwood was retained until overstory removal and its value therefore deferred and discounted to the present; (2) the cost of underburning in the shelterwood was greater than that of broadcast burning in the clearcut; (3) the cost of seedlings and planting was higher for clearcutting (larger seedlings, auger planting) to account for the relative harshness of the site; and (4) costlier hand piling after overstory removal was necessary in the shelterwood. NPV of the existing stand is greater for the clearcut than shelterwood alternative, as is NPA, but SEV is slightly more negative because of the higher seedling and planting costs in future rotations (Table 7). The delayed overstory removal and hand-piling costs associated with the future-rotation shelterwoods have comparably less impact than do planting costs, when amortized over 125 years. Curiously, stumpage values (in cunits) of future-rotation harvests are nearly identical—about $137 per cunit—for clearcut and shelterwood alternatives. If cable logging is to be used in the future, it is likely that the future stumpage values for the shelterwood alternative will be lower to reflect normal differences in logging costs between the two alternatives.

Table 7. Cash-flow analysis for the Center Ridge timber sale (Teubner 1983).

Year	Operation	Cash flow/ acre ($)	Year	Operation	Cash flow/ acre ($)
	Clearcut alternative			**Shelterwood alternative**	
0 *	Clearcut (33.8 cunits @$103.20/cunit)	+3,488	0 *	Harvest shelterwood (14.6 cunits @$13.01/cunit)[1]	+190
2 *	Broadcast burn	- 227	2 *	Underburn	- 252
3	Plant (auger)	- 245	3	Plant (hoe)	- 220
	Bait gophers	- 45		Bait gophers	- 45
5	Release (aerial spray)	- 65	5	Release (aerial spray)	- 65
15	Precommercially thin	- 90	8 *	Remove overstory (19.2 cunits @$156.04/cunit)	+2,996
	Treat slash (hand pile)	- 50		Treat slash (hand pile)	- 70
57	Thin (12.6 cunits @$36.75/cunit)	+463	15	Precommercially thin	- 90
	Treat slash (hand pile)	- 100		Treat slash (hand pile)	- 50
77	Thin (13.2 cunits @$56.14/cunit)	+741	57	Thin (12.6 cunits @$36.75/cunit)	+463
	Treat slash (hand pile)	- 100		Treat slash (hand pile)	- 100
97	Thin (11.9 cunits @$80.25/cunit)	+955	77	Thin (13.2 cunits @$56.14/cunit)	+741
	Treat slash (hand pile)	- 100		Treat slash (hand pile)	- 100
117	Clearcut (65 cunits @$137.32/cunit)	+8,926	97	Thin (11.9 cunits @$80.25/cunit)	+955
119	Broadcast burn	- 227		Treat slash (hand pile)	- 100
			117	Harvest shelterwood (50.7 cunits @$137.47/cunit)	+6,970
	NPV (existing stand)	3,278	119	Underburn	- 252
	SEV (future rotations)	-213	125	Remove overstory (14.3 cunits @$136.92/cunit)	+1,958
	NPA	3,065		Treat slash (hand pile)	- 70
				NPV (existing stand)	2,095
				SEV (future rotations)	-197
				NPA	1,898

[1]This area had been entered before; therefore, the first shelterwood entry in this analysis removed relatively few, low-value trees.

* Asterisked items not included in calculation of SEV.

Example 3—Jill timber sale

This prescription was written for a stand within the Butte Falls Ranger District, Rogue River National Forest (McCrimmon 1986). The 60-acre stand, composed of uneven-aged mixed-conifer forest and on relatively flat terrain, was partially tractor logged in 1972. About 30 percent of the area was stocked with vigorous, naturally regenerated seedlings, and overstory trees were infected with dwarf mistletoe.

Cash-flow analysis for this timber sale uses an interest rate of 4 percent and bases its costs on District experience. However, the analysis of alternatives is somewhat different from that in examples 1 and 2. Here the actual clearcut-shelterwood comparison applies only to the harvest and regeneration of the existing stand and the first rotation. The analysis assumes that existing naturally regenerated seedlings will be protected and managed under both alternatives; that additional planting will be required in unstocked areas, at equal cost per acre for both alternatives, after the clearcut and initial shelterwood entry; that interplanting will be necessary in the shelterwood after overstory removal; and that all future stands will be regenerated by clearcutting and planting. Timber values are assumed to increase at the rate of 1 percent per year for the next 50 years. This set of assumptions and conditions requires a three-component NPA analysis: (1) NPV of the existing stand, (2) NPV of the first rotation (with natural and artificial regeneration, and interplanting after shelterwood overstory removal), and (3) SEV of future clearcut-and-plant rotations.

Analysis (Table 8) shows that the NPV of the existing stand is greater for the shelterwood than clearcut alternative for the following reasons: (1) because predesignated skidtrails will be used, logging costs for the two alternatives are assumed to be equal; (2) given equal logging costs, appraised stumpage values also are assumed to be equal for the clearcut and first shelterwood entry; (3) even though harvest of shelterwood overstory trees is delayed, additional growth of those trees during the "delay" increases the total yield for the shelterwood alternative; (4) moreover, the stumpage value of those trees is assumed to increase. However, the NPV of the first rotation is less negative for the clearcut because the shelterwood alternative requires replanting 20 percent of the site after overstory removal. The SEV of future rotations is the same for both alternatives because both revert to a clearcut-and-plant strategy.

Table 8. Cash-flow analysis for the Jill timber sale (McCrimmon 1986).

Year	Operation	Cash flow/ acre ($)	Year	Operation	Cash flow/ acre ($)
	Clearcut alternative			**Shelterwood alternative**	
0	*Clearcut (16.4 M bd ft @$113/M bd ft)	+1,853	0	*Harvest shelterwood (8.3 M bd ft @113/M bd ft)	+938
	Conduct post-logging/veg mgmt survey	-5		Conduct post-logging/veg mgmt survey	-5
	*Remove undesirable trees	-50		*Remove undesirable trees	-50
1	Plant	-347	1	Plant	-347
	Release (backpack spray)	-80		Release (backpack spray)	-80
	Survey stocking levels	-14		Survey stocking levels	-14
13	Precommercially thin	-207	6	*Remove overstory (10.2 M bd ft @$120/M bd ft)	+1,224
50	Thin (6.7 M bd ft @$112/M bd ft)	+749		*Conduct post-logging/veg mgmt survey	-5
83	Clearcut (34.1 M bd ft @$186/M bd ft)	+6,337	7	*Replant 20%	-162
				Survey stocking levels	-14
	NPV (existing stand)	1,853	13	Precommercially thin	-207
	NPV (first rotation)	-254	50	Thin (6.7 M bd ft @$112/M bd ft)	+749
	SEV (future rotations discounted 83 years to present)	-8	83	Clearcut (34.1 M bd ft @$186/M bd ft)	+6,337
	NPA	1,591			
				NPV (existing stand)	1,905
				NPV (first rotation)	-392
				SEV (future rotations discounted 83 years to present)	-8
				NPA	1,505

*Asterisked items not included in calculation of SEV.

Overall, the NPA is greater when the existing stand is clearcut than regenerated as a shelterwood. Despite the assumed equal logging costs, the replanting cost after overstory removal outweighs the increased yields and stumpage values associated with the delayed shelterwood harvest. In fact, logging costs for the shelterwood would probably have to increase if damage to seedlings is to be avoided during overstory removal. On the other hand, the clearcut areas might have to be replanted because of site exposure. If so, such costs could easily offset the NPA advantage apparently enjoyed by the clearcut alternative.

Final comments

The example cash-flow analyses illustrate how costs and revenues can differ between reproduction methods, but clearly indicate that each silvicultural prescription is unique and should be analyzed on a site-specific basis. Financial returns are generally greater with clearcutting on steep terrain because of reduced logging costs, but returns for shelterwoods can approach those for clearcutting as terrain becomes gentler and predesignated skidtrails are used.

The NPV of harvesting an existing stand today is often the key factor in determining the outcome of an NPA analysis. However, for future stands, costs that accrue late in a rotation have relatively less impact on the outcome of a cash-flow analysis when they are discounted to the present. Costs that accrue early in the rotation and that must be amortized for several decades can significantly influence the economic outcome. In the Jill timber sale, for example, the replanting cost after shelterwood overstory removal appears to be the key factor favoring clearcutting. Of course, replanting a clearcut will also negatively affect cash flow.

The Jill timber sale also illustrates that growth of shelterwood overstory trees, along with price increases over time and perhaps increases in log value as trees get larger, can offset the discounting effect associated with their delayed harvest.

Let us reiterate that, although these were actual silvicultural prescriptions comparing the two methods on specific sites, we do not suggest that selecting a reproduction method is as simple as conducting a cash-flow analysis. There are situations in which one or the other of these reproduction methods may not be a logical alternative because of other land-management objectives or ecological considerations. A cash-flow analysis is but one piece of information a manager can use in making a decision.

Chapter 8: Selecting a Reproduction Method for Reforestation Success

As evident from this report, both the clearcut and shelterwood methods represent viable options for regenerating commercial forest lands in southwest Oregon. How, then, do land managers determine which method is appropriate?

We maintain that a logical decision-making process must be followed—one that blends the technical information presented in this report with the multidisciplinary goals and constraints of a land-management organization. It is crucial to thoroughly evaluate the entire reforestation scenario for an area, from regeneration cut to established seedlings, before a stand is ever entered (Jaszkowski 1975, Shepard and Larsen 1985, Tesch 1985). In some cases, such a decision-making process will reveal an obvious choice. In others, reforestation success may be reasonably assured with either method, and the choice boils down to one of personal preference.

Requisites for Decision-making

The decision-making process typically includes interaction between a management decision-maker and technical staff. Regardless of the size or composition of such groups, we find the following requisites:

- **Land management objectives must be specified:** Organizational goals and policy must be clearly understood at the outset. In some cases, objectives are identified in formal land-management plans; in others, the personal philosophy of the management decision-maker may influence alternatives. Such input should clarify social, legal, and political factors, and guidelines for the roles of time, money, risk, and personnel skill and availability. Establishing even broad objectives can help foresters more efficiently integrate site and stand information to develop ecologically sound reforestation plans.
- **Technical expertise from different disciplines must be made available**: For any land-management objective, foresters must integrate technical information about many resources into a reforestation plan. Input from experts in different disciplines, whether a team or individuals, is critical for consistent success—a breakdown in any one of the many aspects of the reforestation process may result in failure. For example, proposed silvicultural strategies must be ecologically, physically, and economically feasible to implement, especially from a harvesting perspective. Strategies for disposing of slash must balance fire hazard and possibly impaired site accesss for tree planting against the importance of retaining such woody debris for site productivity. Pest management problems can often be ameliorated by favoring different tree species, or by altering stand structure or density.

Integrated consideration of the following subject areas is important in both decision-making and planning for implementation, even though the significance of each area may vary from one project to another (Tesch 1985):

- Silviculture
- Sociology
- Economics
- Geology
- Soils
- Hydrology
- Wildlife
- Civil engineering
- Logging engineering
- Timber sale administration
- Fire management

Clearly, such an interdisplicinary approach also assists in meeting land management objectives other than reforestation.

- **Ecological attributes of the site must be identified:** Knowledge of key environmental characteristics, the existing plant community, and future successional trends is critical for selecting a reproduction method that can accommodate the biological requirements of the species being regenerated. Activities necessary to create a favorable environment for seedling establishment must be determined, and their ecological impacts, operational limitations, and costs considered. Both the activities required for harvesting the existing stand and those required for establishing and tending the future stand must be accounted for. Projection of future site conditions may be based on a combination of information collected from the site, published data, and reforestation experience on similar sites.
- **Recommendations must be forwarded to the decision-maker**: Recommendations made by technical staff and interdisciplinary experts about reforestation alternatives should be presented to the decision-maker, who evaluates the scenarios in light of organizational goals (Devlin 1985). Such a process should ensure that selection is based on a full awareness of the requirements for success, potential known weaknesses, and a commitment on the part of management to provide the resources necessary to implement the selected alternative.

Monitoring and Standards

Once a reforestation plan is implemented, sites must be monitored to ensure that the original land-management objectives are being met. For a monitoring program to work, land managers and, perhaps to an increasing extent, society must agree on clear, tangible standards against which success can be measured. Some standards, such as one for timber (number of established seedlings), are relatively easy to define. Others, such as those for biodiversity, wildlife habitat, or social acceptability of practices, may be difficult to quantify.

Often, standards are set by agency policy or law, and some monitoring is required. The Oregon Forest Practices Act, for example, requires that a minimum of 100 trees per acre be reestablished within 6 years after harvest in the interior portion of southwest Oregon. The BLM policy manual, on the other hand, sets stocking standards based on time of first commercial entry; this requires that foresters estimate the mortality between time of planting and perhaps 40 years later when stands are first commercially thinned.

Standards typically include (1) a target for success when everything works as planned, and (2) a minimum standard below which additional action is required. Target levels should account for at least a gross estimate of what is desired in the future stand. For example, to meet timber objectives, the target might be 80 crop trees per acre, average dbh of 24 inches, by age 80; to meet wildlife objectives, the target might be 10 percent of hardwood tree cover, or 2 to 4 snags per acre, or 300 pounds of herbaceous forage per acre for the first 5 years after harvest.

For planning purposes, each reproduction method should be capable of meeting minimum standards under conditions of "reasonable risk." In defining risk, managers should rely on experience to describe realistic conditions—for instance, a 10-year frost cycle as opposed to a more severe, and far less probable, 100-year frost. Minimum standards and reasonable risk should also reflect the cost of replanting a site if stocking is inadequate.

In addition to ensuring that standards are being met, a monitoring program can provide a warning that practices such as vegetation management or animal-damage control are necessary before a catastrophe occurs.

A Planning "Road Map"

One good way to develop and evaluate regeneration strategies is to construct possible reforestation plans for both clearcut and shelterwood alternatives using a flow chart for a "road map." This step-by-step approach helps planners logically consider all important components, observe the linkage between components, and understand how timing and coordination of operations influence success. Such a road map prepared by Shepard and Larsen (1985) illustrates the steps associated with the shelterwood method (Figure 3) and the key relationship between logging feasibility and reforestation success. This road map, coupled with a description of the site and existing stand as well as a statement about future stand structural goals, could be used to stimulate examination of, for example, need for slash disposal, site preparation,

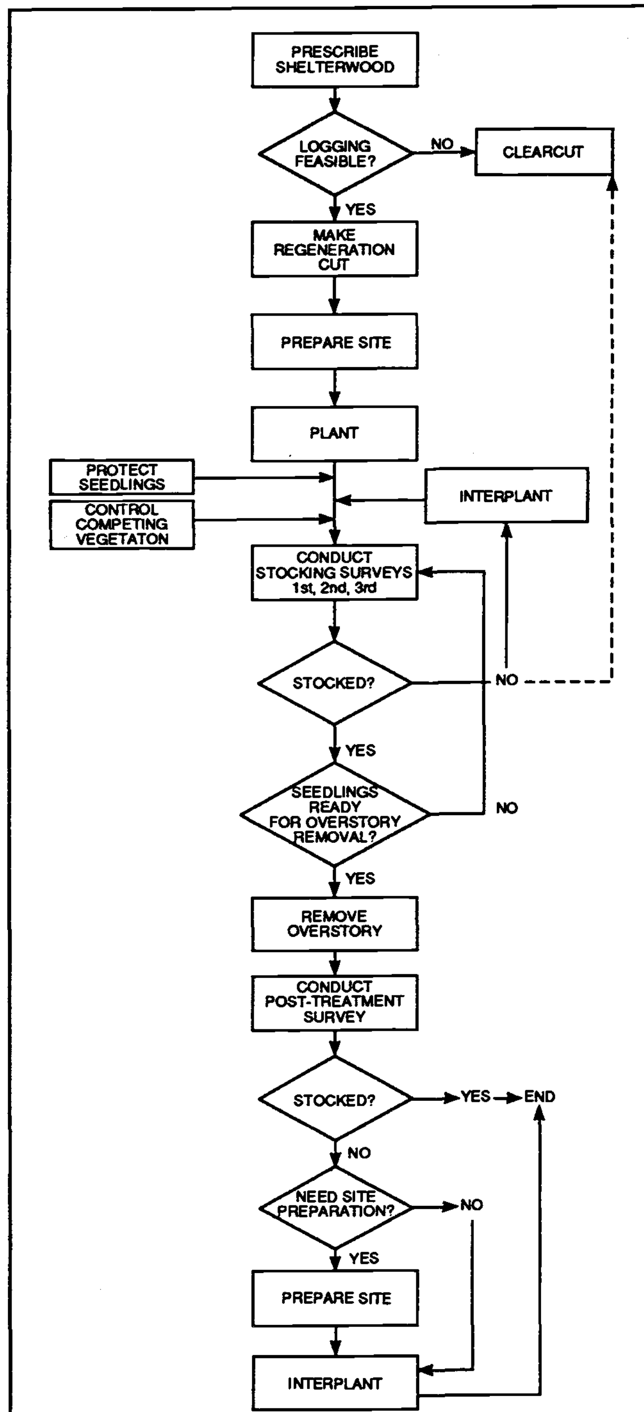

Figure 3. "Road map" to shelterwood regeneration (adapted from Shepard and Larsen 1985). Solid lines reflect pathways for establishing seedlings with the shelterwood reproduction method. The dashed line reflects an alternative for when the existing stand conditions limit the establishment of additional seedlings to reach desired stocking levels or where survival of seedlings at adequate stocking levels is unlikely after overstory removal; foresters may choose to clearcut and restart the reforestation process.

vegetation management, or seedling protection. The requirements for each step could be listed in a table and rated as to ecological, operational, and economic feasibility. Such lists could then be assessed in light of the overall land-management objective to help the decision-maker select an alternative. Cleary *et al.* (1986) have written an excellent planning guide that elaborates on the step-by-step process outlined above for artificial regeneration by planting.

Chapter 9: Concluding Remarks

Both the clearcut and shelterwood methods are viable systems for reestablishing seedlings after harvest in southwest Oregon forests. However, consistent success with either one requires a full awareness of the respective method's attributes. Because of environmental diversity, varying stand conditions, and different landowner objectives, blanket silvicultural prescriptions are impossible. However, given the opportunity to use artificial regeneration in conjunction with either method, we have found few situations in the region where shelterwood management is required, from a biological standpoint, to assure regeneration of at least one well-adapted commercial conifer species on the site.

We recognize that a variety of landowner objectives exists and recommend a logical, interdisciplinary approach to select a method that provides successful reforestation and satisfies the established decision criteria. The key to this decision process is site-by-site analysis and careful planning of an entire operation before any trees are harvested.

A careful match of species to site is always important in prescribing reproduction methods. Most of this report focuses on planted Douglas-fir, which has demonstrated a fairly broad ecological amplitude. Ponderosa pine is well adapted to hot, droughty, low-elevation sites and grows well when planted in a clearcut environment. Other species growing in mixed-conifer forests vary in their silvical characteristics; some are frost resistant, whereas others may require overstory protection. On sites subject to regular growing-season frosts, species selection strongly influences the choice of reproduction method. Shelterwood management is best for promoting a frost-sensitive species such as Douglas-fir or white fir, whereas clearcutting can work if lodgepole, ponderosa, or western white (*Pinus monticola*) pine is acceptable.

The clearcut reproduction method can be successful on hot, dry southwest Oregon sites when seedling quality, planting practices, and vegetation management are adequate. However, when seedling quality, planting practices, or regeneration timing is less than ideal, newly planted seedlings benefit from the shade of a shelterwood overstory.

On droughty sites, herbaceous vegetation reduces seedling survival, especially for Douglas-fir in the first 5 years, whereas shrubs and hardwoods primarily hamper seedling growth. Some control of competing vegetation is typically essential for either reproduction method to be effective in the long run on these harsh sites.

Ongoing studies indicate that survival of planted seedlings is nearly equal for clearcut and shelterwood reproduction methods. However, shelterwood overstory removal remains a major concern and can lead to substantial seedling damage and mortality. Coordinated harvest and silvicultural planning can greatly reduce such damage, especially on steep terrain. Research is underway to develop tools to project the outcome of overstory removal before beginning shelterwood operations.

It is a fact of life that artificial regeneration by planting is more complicated and less efficient in a shelterwood than in a clearcut. It requires more skilled personnel and is typically more expensive, although the cost effectiveness of the two methods becomes more similar on gentle terrain where cable logging is not required. When shelterwood management is selected, the increased complexity and cost must be recognized and a commitment made to provide the needed resources.

The shelterwood method is not a panacea for addressing long-term aesthetic constraints. Traditional shelterwood practices remove overstory trees within about 5 years of planting, leaving a site that looks much like a clearcut of equal age. Delaying overstory removal until seedlings are large and visible slows seedling growth and increases the potential for damage to seedlings when the overstory is removed. When overstory trees are retained throughout a rotation, yield losses associated with the developing stand are not well known, but are presumed to be substantial. Total stand growth will be best if the overstory trees retained are vigorous and capable of increased net growth.

Planting seedlings in clearcuts and under shelterwood overstories is the most dependable means of promptly regenerating stands. Observations document the success of natural regeneration in some situations, but often over longer periods. With natural regeneration, shelterwood shade becomes increasingly important on steep, south-facing slopes where high soil-surface temperatures can be anticipated, and in frost-prone areas. Extending the acceptable regeneration period from 5 to 10 or 15 years and utilizing natural regeneration may reduce the initial costs of artificial regeneration on some sites, but this strategy must be viewed carefully case by case to evaluate the impact of reforestation delay on possible vegetation-management problems, the likelihood of understocking or overstocking, and the potential for significant increases in rotation length.

Clearcutting has probably been favored historically by many land managers because of its economic and operational efficiency in meeting timber management objectives. It may not, however, be the future method of choice as other resource values and objectives increase in popularity. The challenge to foresters for the 1990s is to innovatively apply known ecological principles to meet multiple resource objectives—including timber production, particularly on public lands. Ingenuity in applying both the clearcut and shelterwood reproduction methods will surely be necessary to meet increasingly complex land-management strategies.

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Clearcut and shelterwood reproduction methods are both important, silviculturally viable reforestation tools for southwest Oregon. The ecology of local forests lends itself to the successful application of either method, in most cases; thus, choice of method is typically based on land management objectives, which integrate social and resource values, economics, and administrative, political, and regulatory considerations. This report summarizes the available research and experience information base for the two methods so that ecological, operational, and economic trade-offs can be better understood. Most of the information focuses on planted Douglas-fir, although material on natural regeneration and other species also is presented.

Keywords: Reforestation, reproduction method, harvesting techniques, regeneration, economics, operational practices, land management objectives, reforestation planning.

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