9 Harvesting Timber to Achieve Reforestation Objectives

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INTRODUCTION

Besides providing a commodity, timber harvesting alters the characteristics of an existing stand on a forest site. The nature of this disturbance varies widely depending on the approach to harvesting and the equipment used. When the harvest is carefully planned, the disturbance can be managed to help meet other resource objectives, especially over the long term. The harvesting operation can help provide the operational environment necessary to promote reforestation and the development of target species and stand structures. In fact, timber harvesting is one of the few tools available to silviculturists for making significant alterations to current species composition or stand structure if management objectives should call for this. Others on the short list of such tools are prescribed burning, machine site preparation, and application of fertilizers and chemicals (Tesch et al. 1990).

Harvesting strategies fall generally into two main categories: those in which all trees are removed and those in which some trees are left in place. Both these strategies can be managed to promote successful reforestation. In the first case—clear-cutting—the chief considerations are operational efficiency and ease of reforestation. In the second—a set of harvesting techniques associated with the range of regeneration methods from shelterwood through group selection to single tree selection—more care is required to promote a favorable environment for new trees while protecting existing regeneration and residual trees.

The methods chosen to accomplish non-clearcut harvesting methods will vary depending on silvicultural objectives and on whether residual trees will be retained for relatively short periods (as in conventional shelterwood management) or for the entire rotation (as in some alternative silvicultural proposals such as those being explored in the Forest Service's New Perspectives program). Operational costs and the skills required of personnel will also vary with frequency of entry, ruggedness of the terrain, amount and type of residual to be retained, and other factors.

Understanding the importance of harvesting in relation to reforestation is best approached in an interdisciplinary manner. Coordination between harvesting specialists and silviculturists is essential; since harvesting is a part of silviculture, the silvicultural prescription must include the harvesting plan. Preparing a timber harvesting plan without dialogue between the two disciplines often leaves a site poorly prepared for reforestation, with resulting higher costs of site preparation and planting. Equally ill-conceived is the silvicultural prescription prepared without harvesting input. Such a prescription may accomplish some of the silvicultural goals, but at unnecessarily high harvesting costs. The harvest planners—whether in public agencies or private industry—must be good communicators and must understand the capabilities and limitations of harvesting systems. Also, sufficient care must be given to inspection of the logging operations.

In addition, good communication between the harvesting specialists and the sale administrator is necessary to make sure the job is done

Table 9-1. A comparison of characteristics for harvesting systems used in southwestern Oregon and northern California.

Comparison factors	Harvesting system		
	Ground-based	*Cable*	*Aerial*
Yarding direction	Flat to downhill	Up- or downhill	Up- or downhill
Yarding distance (Practical maximum)	1,200 ft	4,000 ft	7,500 ft
Ground disturbance	Most	Minimal	Landing/service areas only
Costs	Lowest	Higher	Usually highest
Control over residual stand damage	Good	Fair	Best
Forest worker safety	Safe	Dangerous	Fairly safe
Production levels	Low-medium	Low-high	High-very high

according to the plan. The final key to success or failure is the people who do the actual timber harvesting work. Future management options for the stand ultimately rest in the hands of equipment operators, timber cutters, and choker setters. These workers must understand the objectives and desired results of each harvesting job. Their cooperation and conscientious effort while cutting and moving logs from stump to landing is essential in making the logging techniques dovetail en-vironmentally and economically with the reforestation plan.

This chapter will not be a rigorous treatment of harvesting technology. That topic is a textbook in itself, and since several such texts already exist (Studier and Binkley 1974, Conway 1982, Stenzel et al. 1985), readers can seek these and other sources to find specific information about harvesting technology. The chapter will instead concentrate on how harvesting interacts with the reforestation process in southwestern Oregon and northern California. Our discussion focuses in particular on the array of regeneration methods that call for retaining overstory trees and surviving regeneration beneath the canopy; both because, for a variety of reasons, they are being prescribed more and more, and because achieving reforestation in the context of such methods tends to require more harvesting care and skill than does regenerating after clear-cutting. The chapter includes a short review of harvesting methods used in the region, a discussion of timber harvest planning as it relates to reforestation, a discussion of the reforestation implications of harvest operations, and a brief treatment of these concerns as they apply in particular to uneven-aged and alternative silviculture.

A REVIEW OF HARVESTING SYSTEMS

Timber harvesting is both a manufacturing process and a transportation process. Standing trees are felled and manufactured into logs. Value is added to the product along the way—logs on the ground, bucked into lengths preferred by the sawmill, are worth more than standing trees. Logs must be transported, first from the stump or felling site to a landing area (primary transportation), and then by truck, rail, or water to a processing facility (secondary transportation). Primary transpor-tation is the aspect of harvesting that has

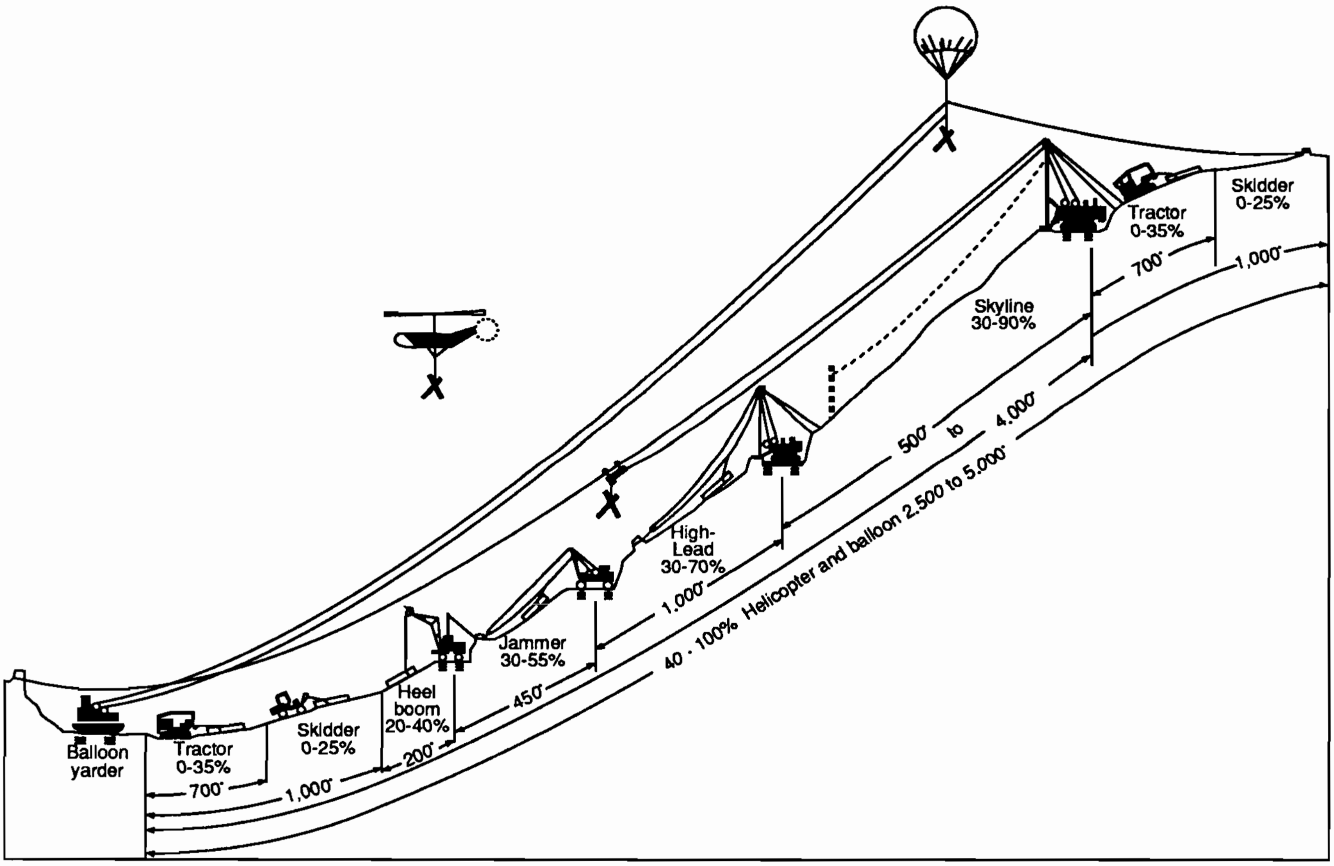

Figure 9-1. Optimum yarding distances and slope percent for different logging systems used in southwestern Oregon and northern California. From Studier and Binkley (1974).

the greatest impact on the forest site and the operational environment for reforestation. To be sure, well-planned harvesting operations must integrate both primary and secondary transportation systems; selection of one harvesting system over another will affect road density, for example, which in turn affects the ability to use prescribed fire. However, this chapter will concentrate on the connection between primary transportation and regeneration.

The various timber harvesting systems in common use in the region fall into one of three categories: ground-based (tractors and skidders), cable (highlead and skyline), and aerial (mostly helicopters). Each of these has its own capabilities, limitations, costs, and effects on the site. A good understanding of the capabilities of each system is essential if the operational environment for reforestation is to be optimized. Figure 9-1 gives a schematic display of yarding distances and terrain limitations for the basic harvesting systems. A comparison of the amount of ground disturbance caused by each is shown in Figure 9-2. Other characteristics are compared in Table 9-1.

Ground-based Systems

Yarding, or primary transportation, is defined as the initial movement of logs from the felling site to a landing area in preparation for further transport. In a ground-based yarding system, the yarding machine travels to or within winching distance of each log being yarded. Yarding can be done by animals (mainly draft horses), tracked vehicles—including both rigid-tracked machines (crawler-tractors) and flexible-tracked machines—and four-wheel-drive articulated tractors (rubber-tired skidders). Yarding with horses has been done

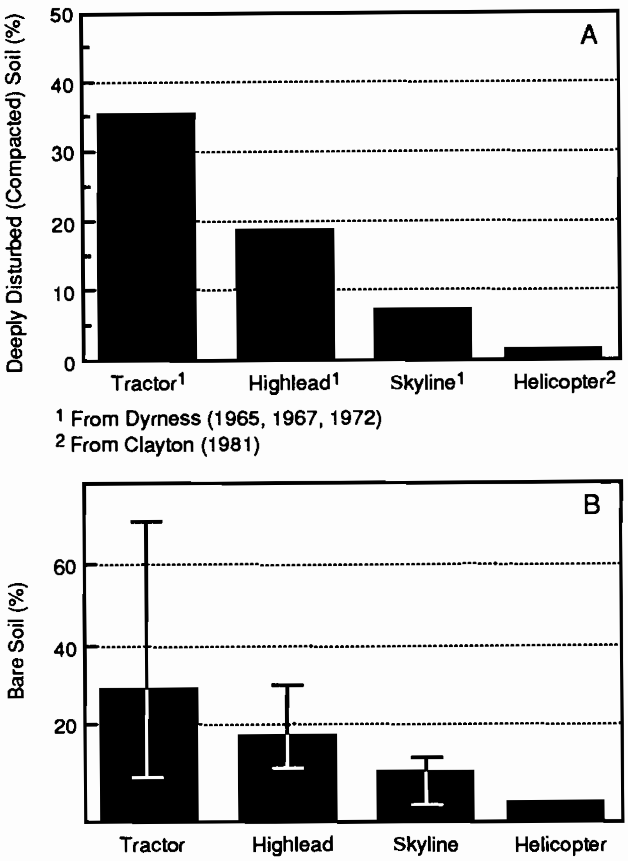

Figure 9-2. Comparisons of soil disturbance from different logging systems. Ranges are also shown. (A) Percent compacted. (B) Percent mineral soil exposed.

recently in southwestern Oregon, but the practice is typically used only in small-scale operations and in areas where mechanized systems are restricted. Most ground-based yarding in the region is done with machines.

Ground-based systems are usually the least expensive of all the harvesting systems when applied to the appropriate terrain—flat or gently sloping ground. On steeper terrain, ground-based systems can be not only more costly but operationally more difficult and more dangerous for workers. Practical limits to the slope of the ground are usually considered to be about 40 percent for tractors and 25 percent for skidders. These limits are not absolute; ground-based logging vehicles can sometimes be used on steeper slopes if the steep areas occur in short pitches with generally more gentle slopes surrounding them. A key question when considering the use of ground-based machines on steeper slopes is whether or not skid trails will be excavated into the hillside. Excavated skid trails are safer because they are more level, but they can be unsightly and can cause soil displacement.

A key environmental concern in harvesting with ground-based equipment is soil compaction. Compaction by ground-based logging equipment has been shown to reduce tree growth (Perry 1964, Foil and Ralston 1967, Moehring and Rawls 1970, Holman et al. 1978, Froehlich 1979, Wert and Thomas 1981). The amount of growth reduction on a given site depends on the increase in soil density, depth of compaction, and percentage of compacted soil around the roots. Severely compacted soils may also impede tree planting.

Crawler-tractors, rubber-tired skidders, and draft animals vary in their compacting effect on the soil when only the first five passes are considered. However, when more passes are made (as on any main skidding trail), the resulting total soil compaction is often not significantly different among the three operations (Froehlich 1980). The most effective way to reduce soil compaction in ground-based operations is to designate skid trails so that the area affected by the skidding machines is kept below 10 percent of the total harvesting area (Garland 1983). Properly designated skid trails can also increase the efficiency of logging operations.

Cable Systems

Cable yarding systems have proved their usefulness in the mountainous terrain of the region. Cable systems transport logs from the felling site to a landing area by a yarder equipped with multiple winches. In contrast to ground-based logging, the yarder remains in a stationary position. Long lengths of wire rope are spooled off the yarder's winch drums and suspended over the harvesting area to transmit the pulling forces necessary to move logs.

Cable systems, once used mainly to log clearcuts, are well suited to yarding other types of

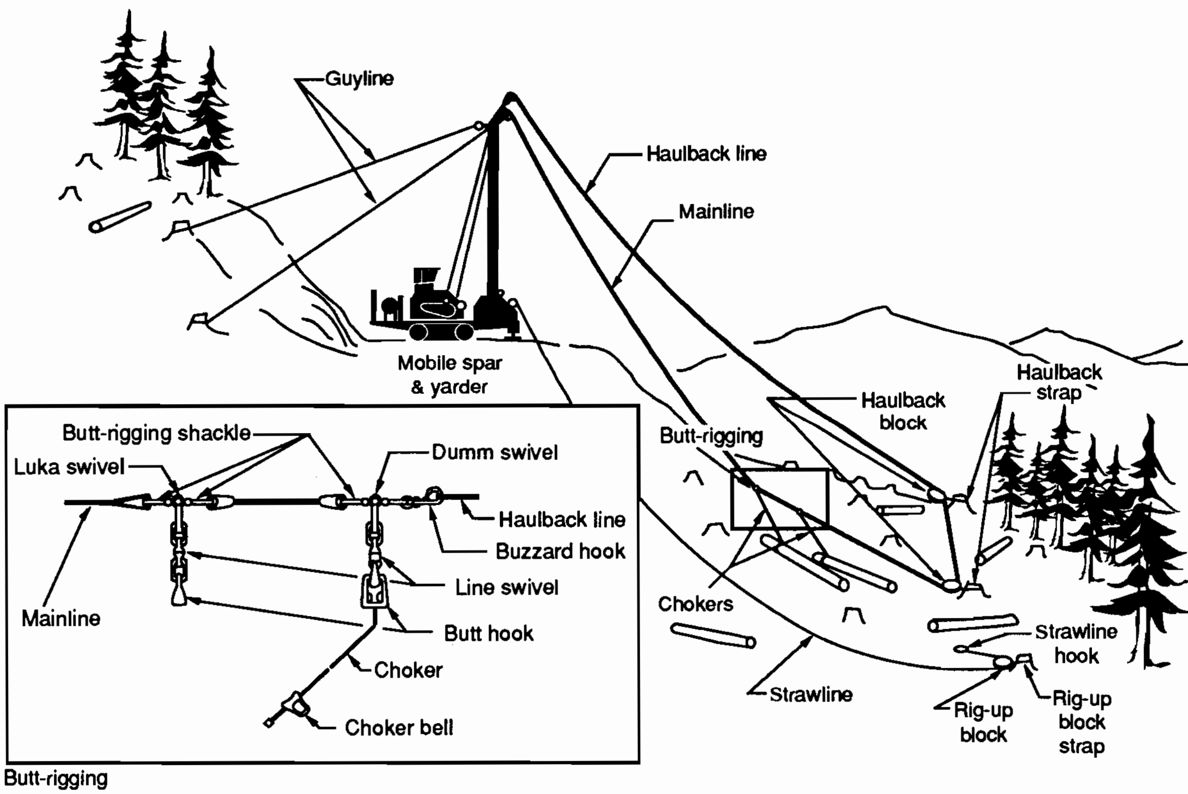

Figure 9-3. The highlead yarding system. From Studier and Binkley (1974).

harvest patterns as well. Cable systems have advantages in areas where ground-based systems are inadvisable because of traction, stability, safety, and site-impact considerations. Depending on the yarding system, logs can be pulled uphill, downhill, or along the terrain contour. Yarding distances of more than 5,000 ft are possible, but a more realistic average maximum for systems used in this region is about 2,000 ft. These long yarding distances give cable systems two important advantages over ground-based systems: (1) fewer haul roads are needed, and (2) ridgetop roads can be used; these minimize soil movement, lessen the visual impact of roading, and provide ready-made fire breaks in strategic locations. In general, cable logging results in less site disturbance than ground-based systems, but it tends to be more expensive.

Highlead

The highlead system is the simplest form of cable logging used in the region. This system has two operating lines, the mainline and haulback line. These are connected at the butt-rigging, a series of swivels and other hardware that keep the lines from twisting. The butt-rigging also serves as the attachment point for the chokers that are fastened around the logs being yarded (Figure 9-3). The mainline pulls the butt-rigging and logs to the landing, and the haulback line pulls the butt-rigging and mainline back to the logging area for the next turn of logs. Lateral yarding—bringing logs from the side of the cableway into the path of the mainline—is limited to the length of the chokers. Therefore, the highlead method is best used for clear-cutting. It is not well suited to regenera-

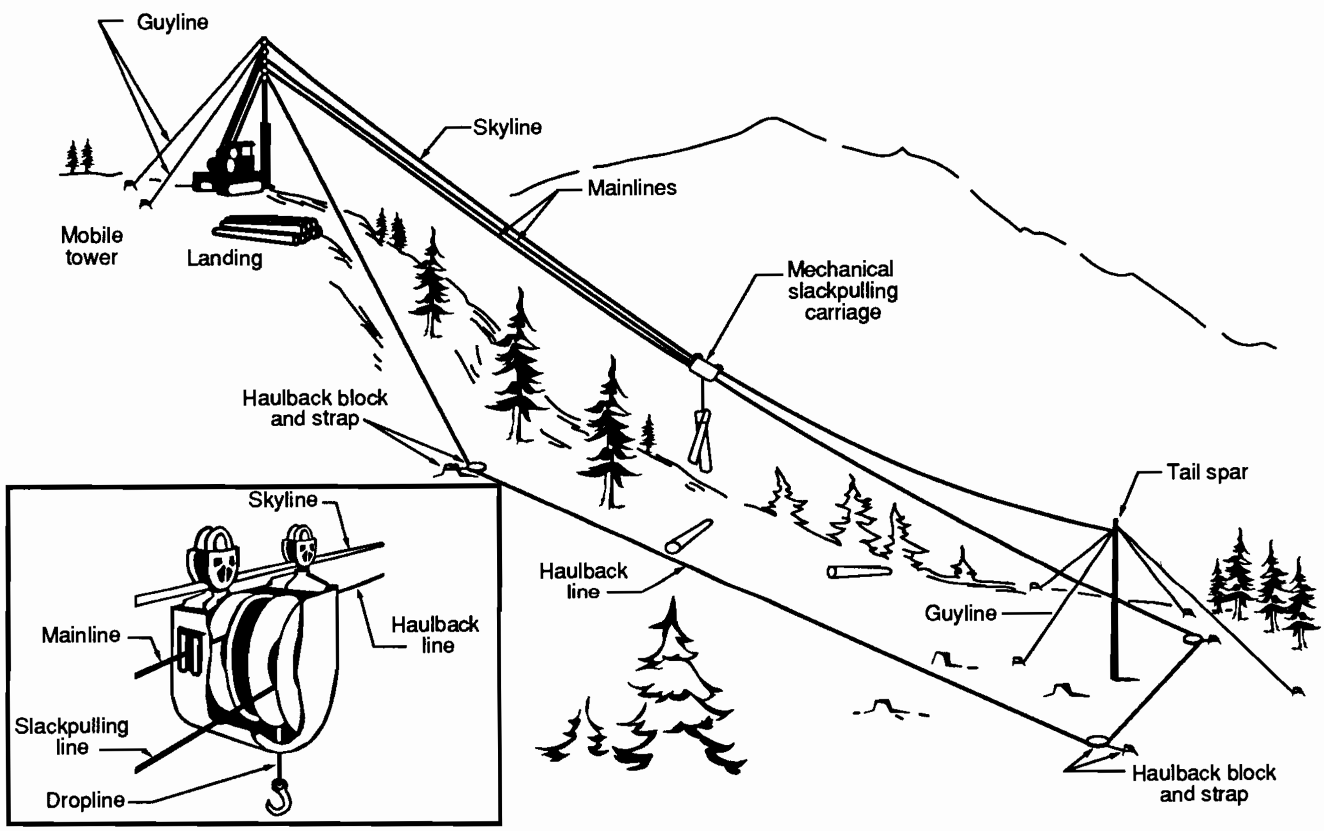

Figure 9-4. A typical skyline yarding system. From Studier and Binkley (1974).

tion methods in which overstory trees are retained or survival of seedlings or advance regeneration is desirable.

The highlead system is, for the most part, a ground lead system; the entire length of the log is skidded along the surface of the ground. One end of the log can be lifted clear of the ground if necessary; to accomplish this, the yarder operator applies the brakes to the haulback drum while pulling in on the mainline drum, a procedure called "tightlining." However, this procedure is hard on yarding equipment and is usually done for only short distances to avoid obstructions. Thus, highlead logging can cause considerable disturbance to the soil and to logging slash. This may be an adverse impact in steep areas with highly erodible soils. If soil erosion is not a major concern, the highlead method can often provide some site-preparation benefits, sometimes negating the need for prescribed burning or mechanical site-preparation treatments.

Skyline

In skyline logging, a cableway, the skyline, is suspended between two points to serve as a track for a block or carriage (Figure 9-4). Because skylines can be used to yard timber from difficult harvesting sites with very little soil disturbance, they are an important improvement over the highlead method. Appropriately rigged skylines can also yard logs laterally to the skyline corridor. Logs are then moved along the skyline either completely suspended or with one end on the ground, depending on topography and type of equipment used. Logs can be moved either up- or downhill. These capabilities make skylines applicable both to clearcutting and to situations in which some portion of the existing stand is to be retained.

Many different types of skyline yarders and rigging configurations are available. The important thing for silviculturists to know is that skyline systems will generally cause less soil disturbance on a

Table 9-2. A comparison of highlead and skyline cable yarding systems.

Highlead characteristics		*Skyline characteristics*
	Rigging	
Uses butt-rigging to connect main and haulback lines and chokers.		Uses carriage to ride the skyline and as choker connection point.
	Lift	
Limited lifting capability, unless drum brakes can maintain tension in lines-a ground lead system.		Greater lifting capability with shelterwood; full suspension of logs possible.
	Lateral reach	
Lateral yarding distance limited by choker length.		Depending on carriage design, can accomplish lateral yarding.
	Silvicultural system	
Principally a clearcut system.		Can be used for all situations.
	Soil disturbance	
Because a ground lead system, more soil disturbance expected.		Because of suspension capabilities, less soil disturbance.
	Yarding cost[1]	
Generally more expensive than skyline at longer distances.		Because of better outhaul speed and suspension, about 50-75% less than highlead.
	Production[1]	
Good for short distances, but generally less than skyline.		Depending on distance and other yarding conditions, 25-100% greater than highlead.

[1] Adapted from Dykstra (1975).

given site than either ground-based or highlead systems. Some pertinent comparisons between the highlead and skyline systems are shown in Table 9-2.

Aerial Systems

Aerial harvesting systems, those that employ helicopters and balloons to yard timber, are less common than other systems. Because balloon logging is very uncommon, we will concentrate on helicopters in this discussion, but the concepts of vertical-lift logging apply equally well to helicopters and balloons.

Helicopters were first used for timber harvesting in the region in the early 1970s. To date they have accounted for only a small portion of the total timber harvest because they are typically more expensive than other harvesting systems. This situation may change dramatically in the future, however, as environmental and aesthetic concerns become more important.

Aerial harvesting operations are considerably different from ground-based or cable systems. A typical helicopter yarding cycle consists of (1) flying from the landing to the log pick-up area, (2) hovering over the logs while a worker on the ground attaches chokers to a hook at the end of a cable, (3) lifting logs out of the pick-up area, and (4) returning to the landing where the logs are electronically disengaged from the hook. Often another light-utility helicopter returns chokers to the rigging crews as required. Operations are interrupted about once an hour for refueling and twice a day for scheduled maintenance.

Because high volumes of timber can be moved in a short period of time with helicopters, two or more landings will often be used. The helicopter can either alternate between landings or fill one landing completely and then move to the other.

Roads themselves can be used for landing logs, but safety concerns and other operational difficulties can arise.

The aerial system is less constrained than other harvesting systems by yarding distance and timber volume per unit area. A helicopter can often economically yard logs a mile or more. Very low timber volumes per acre are acceptable provided the volume is in relatively large logs or concentrated in a few areas, or both. Yarding with helicopters is dramatically more costly if many small pieces must be gathered together to make up a load. One or two relatively large trees per acre may prove to be quite economical to yard, while many small trees per acre may not (Studier and Neal 1990).

Fog, shifts in wind direction, or other weather-related problems can greatly affect the cyclical operation of aerial logging. Also, machines may not be available when and where they are needed. On the plus side, aerial logging causes none of the ground disturbance associated with other harvesting systems. Moreover, damage to the residual stand is negligible because logs are lifted straight up and flown to the landing free of the ground. Some other advantages are:

1. Little, if any, road construction is needed in aerial systems.
2. They can be used on any terrain.
3. They can be used in both even-aged and uneven-aged silvicultural systems.
4. They can work in highly sensitive visual-resource areas where other systems would not meet management objectives.
5. They can move large volumes quickly and are thus well suited to rapid harvest of timber damaged by fire, insects, and disease.

HARVEST PLANNING TO ACHIEVE REFORESTATION OBJECTIVES

The plan for timber harvesting cannot logically be isolated from the other planning steps important to reforestation success (Mann 1985b). Each step is interrelated, with harvesting used to accomplish much of the work that must be done to meet silvicultural objectives. When resource managers of different disciplines work together to plan a silviculture project, they must understand how the harvesting operation will contribute to achieving silvicultural objectives and, conversely, how silvicultural requirements influence the harvesting operation.

Harvest Planning Philosophy

In all harvesting operations, no matter what type of equipment is used, some "logging footprint" is imposed on the ground. The character of this footprint, or area of disturbance, depends on the harvest plan. For instance, the footprint left by ground-based yarding systems consists of the area disturbed by skid trails, landings, and access roads used to remove timber. For cable systems, the footprint is limited to roads, landings, and the small areas of the skyline corridors (or highlead roads). In aerial systems, the footprint is minimal and consists of access roads, if needed, and landings. In all operations, of course, the impact of the falling trees must be considered as part of the footprint.

The area covered by the logging footprint is the area with which protection measures and ameliorating steps are concerned. In brief, managing harvesting operations in the context of regeneration methods consists of ensuring that this footprint provides the best possible operational environment for successful reforestation.

Selecting the Harvesting System

The fundamental principle in selecting a harvesting system is to choose one that lends itself to both site conditions and the management objectives for the site. To arrive at the best possible match, three different but related questions must be addressed:

1. What is the *physical* feasibility of this system? Can the harvest be accomplished readily, with a reasonable expenditure of energy, while creating a good operational environment for successful reforestation?
2. What is the *economic* feasibility of this system? Will there be an acceptable return on investment? Will some other system be less expensive in the long term?
3. What is the *operational* feasibility of this system? Are the equipment and the harvesting

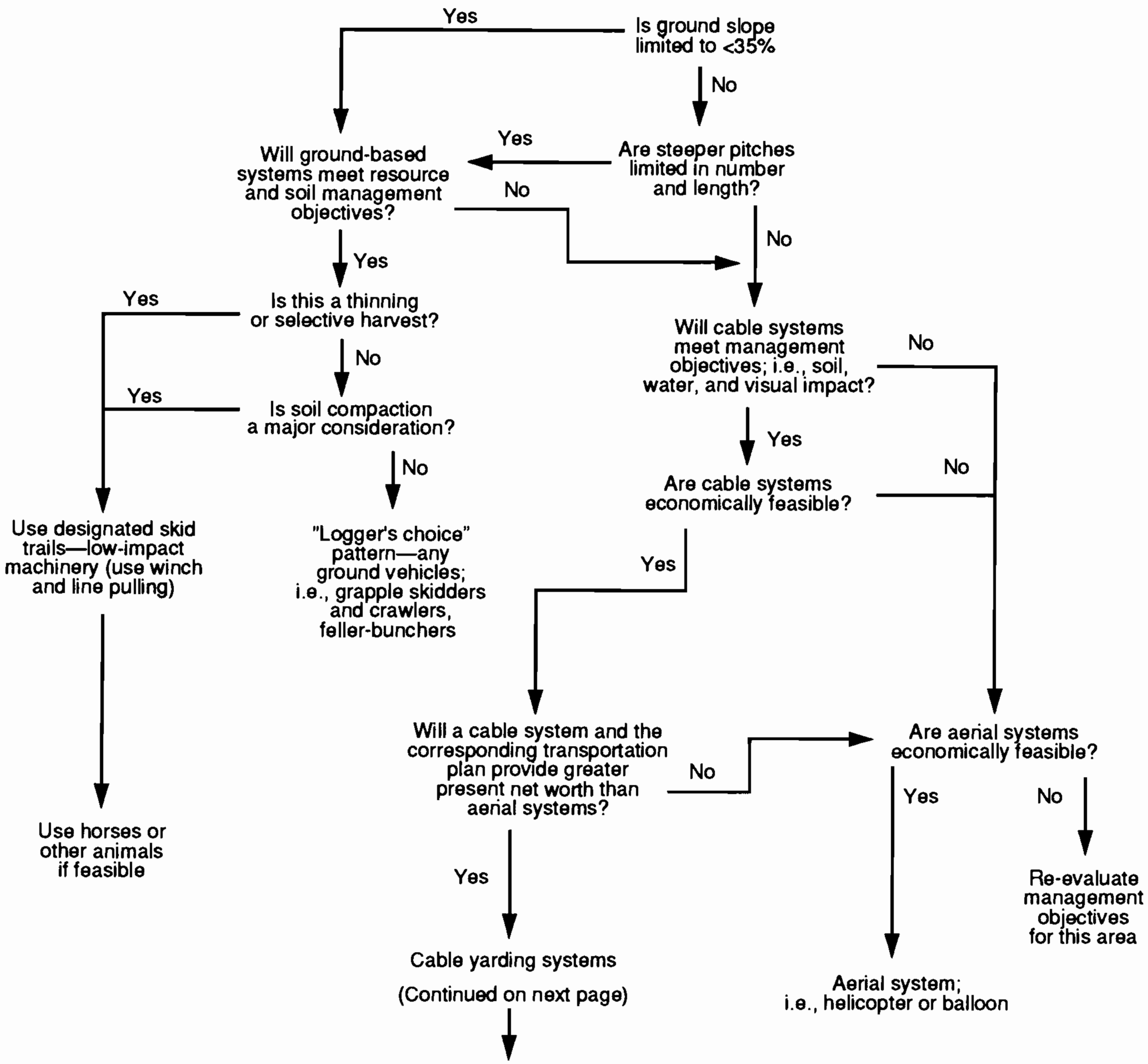

Figure 9-5. Flow chart for matching harvesting system to site and management objectives.

expertise available in the immediate area sufficient to do the job, or will specialized equipment and specially skilled workers have to be brought in?

Developing answers to these questions is not always a straightforward analysis. More often it is a complicated process in which many different factors must be weighed. However, there are several identifiable points at which decisions must be made (Figure 9-5). Thoughtful choices at these points will lead planners toward the best harvesting system or systems for a given situation. Planners must thoroughly understand the intricate operational and economic details of harvesting in order to make consistently good choices.

When silvicultural prescriptions require retention of some portion of the existing stand, the characteristics of the stand to be left after each

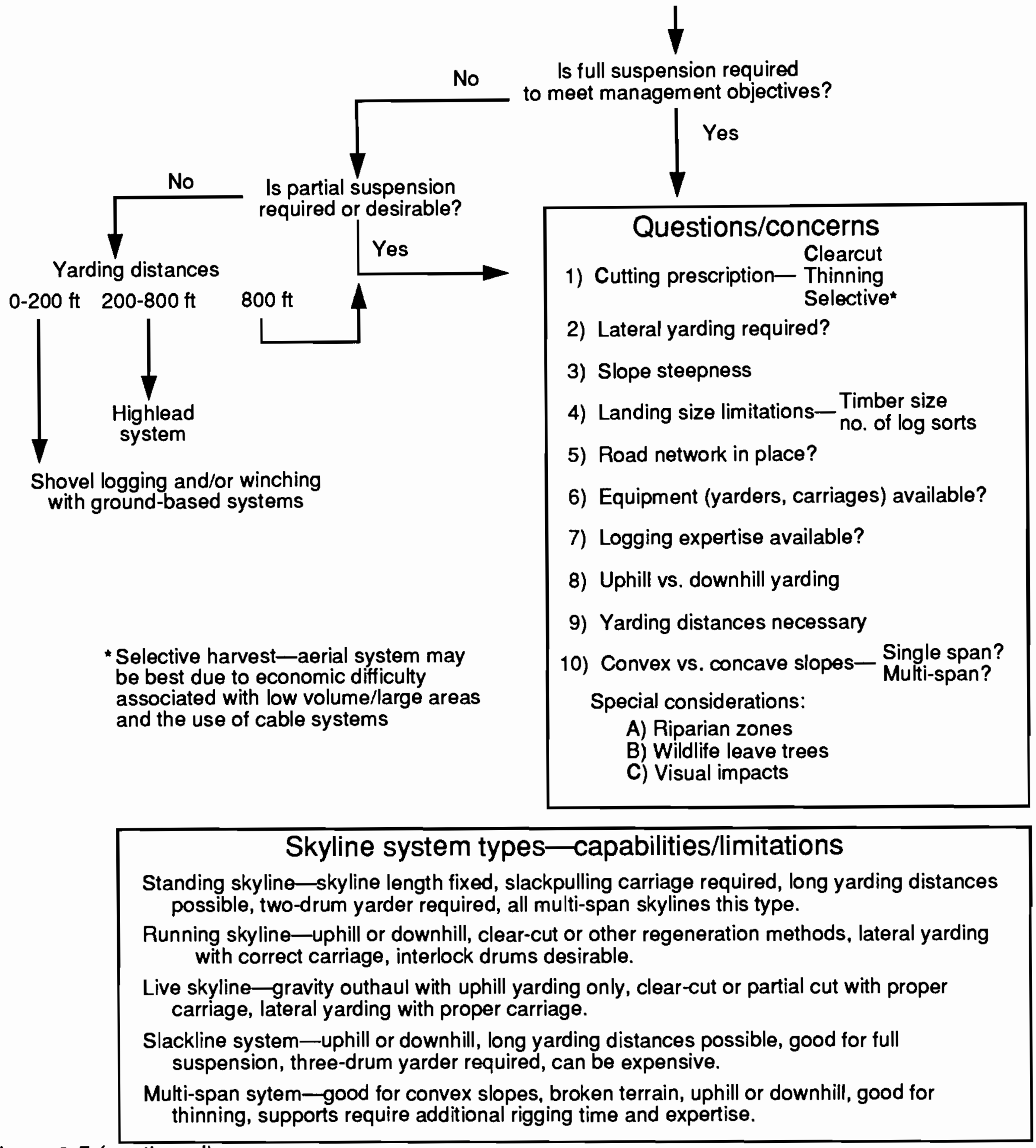

Figure 9-5 (continued).

entry should be assessed. The number, size and distribution of residual trees will influence what can be done in the harvesting operation, whatever system is proposed. The more trees remaining on the site, the greater the difficulty of harvesting operations and the potential for damage to regeneration during subsequent entries.

Here is an example of how data and calculations can be used to help determine the logging footprint within a harvest area, and hence, the need for special harvesting considerations—in this case, determining the need for stage felling in a shelterwood overstory removal. If some assumptions are made based on Paine and Hann's work with crown

Table 9-3. Tree dimensions by diameter and percent of area covered when trees are felled from stands with 50-percent crown ratio.

Species	*DBH (in)*	*Height (ft)*	*Crown width (ft)*	*Area in footprint*[1] *(ft^2)*	*Trees per acre*[3]	*Maximum % of area covered*[4]
Douglas-fir	18	100	30	825	30	57
	24	130	38	1,365	20	63
	30	150	44	1,837	14	59
	36	170	50	2,380	11	60
	48	190	59	3,182	8	58
	60	200	65	3,750	7	60
Ponderosa pine	18	80	25	560	44	57
	24	110	31	962	29	64
	30	130	36	1,332	21	64
	36	150	41	1,762	16	65
	48	160	49	2,280	12	63
	60	180	54	2,880	9	60

1 Area in footprint for trees of various diameters according to model developed in Figure 9-6.
2 Percent of area covered by felled trees = area in footprint x trees per acre ÷ 43,560 ft^2(100).
3 No tree overlaps another.
4 Single-stage felling.

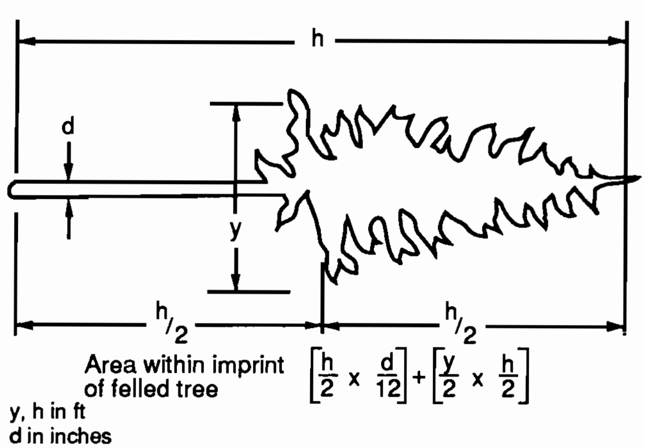

Figure 9-6. Dimension model for felled tree From Mann (1985a and 1985b).

dimensions (1982), the ground area a tree will occupy when it is felled can be estimated (Figure 9-6 and Table 9-3). If significant damage to the understory is expected from felling or yarding, it may be advisable to plan for overstory removal in stages, so that the footprints from the first-stage entry can serve subsequent entries.

Planning the Project

Here are some important points to remember in the project planning phase:

1. Equipment should be suitable to the size of the timber.
2. The logging pattern should be matched to the equipment. For instance, if trees to be removed in either stage of harvest are large and

a log-skidding tractor of the D-7 category is required, skid trails must be at least as wide as the blade of the tractor. If a skyline system is indicated and full suspension of logs is required, a large tower and a large landing area will be needed.

3. Roads should be suitable for all facets of the harvesting operation. Existing or planned roads should be wide enough and aligned appropriately for the type of equipment that will be necessary for the regeneration cut, removal of the overstory, and any intermediate entries required during the next rotation.
4. Equipment should be suited to characteristics of the terrain, timber stand, and surrounding area. If cable systems are used, locate skyline and guyline anchors, tail spars, and intermediate supports in the most effective places.

On gently sloping terrain, minimizing damage to residual overstory trees or regeneration can be accomplished relatively easily with ground-based systems, because more control over logs during felling and yarding is possible than on steeper slopes. Special measures to protect residual trees, such as stage felling and yarding (J.W. Mann, personal communication, 1990; data on file at Forest Research Laboratory, Oregon State University), directional felling (Hunt and Henley 1981), and designated skid trails (Garland 1983), can be used to great advantage. While some of these measures can be employed on steeper slopes, they are less effective and more costly.

The time of year that harvesting is conducted is an important consideration in limiting damage to regeneration. Harvesting in early spring when bark is still quite loose will cause more wounding of stems than logging in late summer or fall. A recent study showed that harvesting in spring, when seedlings were actively growing, caused greater damage to terminal leaders than logging done in late summer and fall after bud set (J.W. Mann, personal communication, 1990). Logging in the winter may help protect seedlings; winter logging on frozen ground may reduce soil impacts, and logging on snow may protect both soil and regeneration. However, winter logging may present scheduling problems.

The susceptibility of regeneration to damage during removal of overstory trees is related to its size. Seedlings between about 30 and 40 inches tall appear most resistant to damage (Tesch et al. 1986a and 1986b). Smaller seedlings, especially planted seedlings, are often seriously injured despite their flexibility. Larger seedlings are less flexible and more inclined to injury due to stem breakage or root damage from being pushed over. Scheduling a harvesting project to coincide with a seedling size "window" will take extra effort to accomplish.

Marking Leave Trees

When it is desirable to remove only a portion of the current stand, it is preferable to mark trees that will be left rather than trees that will be removed. This makes it easier for the marking crew to visualize spacing as they go through the stand, and the markings more clearly show the timber cutters and yarding crew what trees to protect during logging.

Characteristics of desirable leave trees should be carefully specified to the marking crew, or marking operations should be closely supervised by the silviculturist, or both. Leave trees with large crowns are generally undesirable from a reforestation perspective because they can damage regeneration during felling and yarding if they are to be removed during a future entry, and they also may be more prone to windthrow. They can be desirable, however, if they help meet other objectives, such as providing shade for new seedlings. Dialogue between the harvest planner and the silviculturist will be necessary to determine the most important objective in such a case.

How the leave trees are distributed will also have an impact on seedling damage when they are removed. If trees are left in groups, seedling damage can be high in the immediate vicinity of the group when trees are cut. On the other hand, leaving trees in a uniform (rather than grouped) pattern could result in more total seedling damage because of the ground disturbance associated with removing each tree. Operational experience indicates that it is more efficient to leave residual trees in clumps or strips (Figure 9-7). Such patterns will permit safer working conditions around tall snags and trees, limit bole damage to residual trees, increase logging production, leave the harvest unit in a more favorable condition for

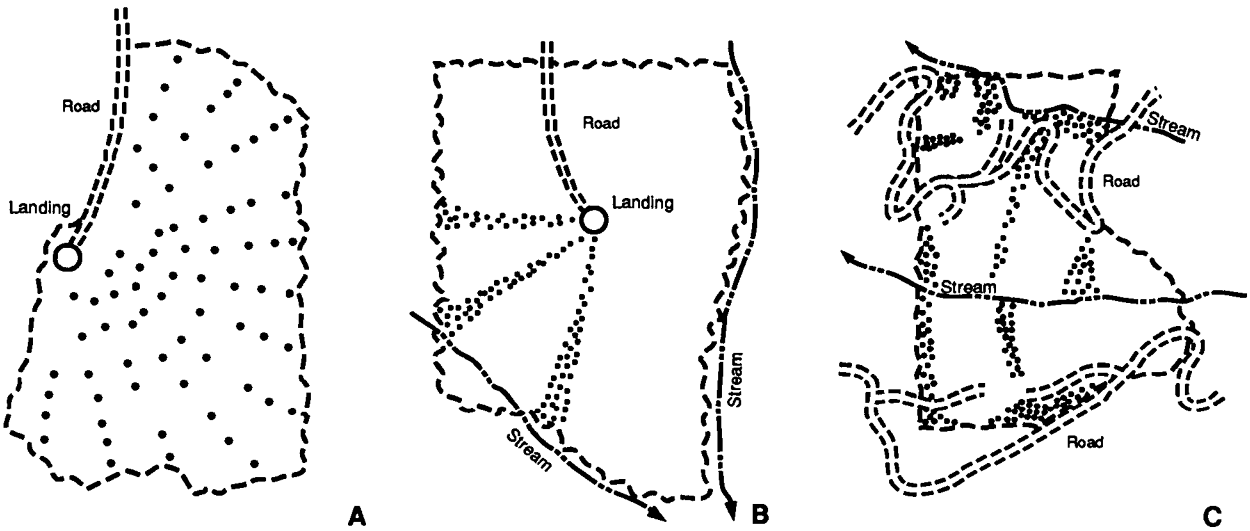

Figure 9-7. Possible leave-tree patterns: (A) Trees left in spokes 15-30 degrees apart, radiating from a common landing. Used in either up- or downhill skyline logging. (B) Trees left in wedge-shaped strips approximately 40 degrees apart, maintaining about 10-15 percent of the timber stand intact. (C) Trees left in specifically chosen areas to provide a mix of species, age and size classes, snag clusters, and riparian areas, representing about 10-15 percent of the harvest area.

slash disposal and site preparation, and allow aerial application of chemicals. Trees left in such patterns may also be more windfirm than those left evenly dispersed.

If portions of the harvest unit are difficult to reach, few or no trees should be left in those areas because yarding may cause excessive disturbance in the final entry. For instance, suppose a long corner exists in a unit such that lateral yarding of 200 ft is necessary to reach the trees growing there. Because pulling large logs laterally over such a long distance will cause much disturbance, all the timber in this area should be taken out in the first entry, before regeneration is established. If overstory trees must be left for shade, it is better to leave smaller trees because they are easier to control during the lateral-yarding phase of overstory removal.

Trees needed for wildlife should be designated before the first entry and maintained throughout the regeneration process. Designation of wildlife trees may have to be adjusted by the sale administrator and logger in consultation with the wildlife biologist in order to provide a safe working environment.

Another important factor to consider on steep terrain where skyline systems will be used is to leave trees that might be needed for logging spars and intermediate supports. Consideration should be given to leaving large, sound trees at the outer edge of the harvest unit. The need for tail spars and intermediate supports will be determined from skyline analysis of the yarding area.

Finally, remember that unsound snags and dead trees with branches present substantial safety hazards for loggers, especially in the vicinity of landings and roads. Overstory trees that are damaged during the regeneration entry should be cut and removed or left as designated wildlife trees.

Designing the Harvest Pattern

Ground-based systems

In ground-based yarding systems, the goal is to cover as small a portion of the cutting unit as pos-

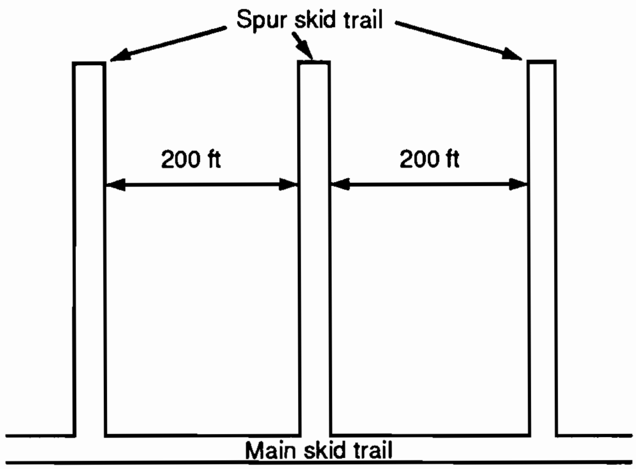

Figure 9-8. Parallel skid trail pattern.

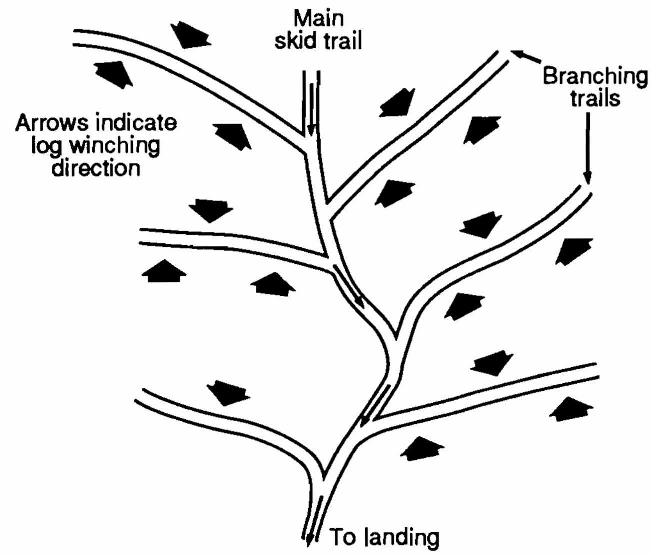

Figure 9-9. Branching skid trail pattern.

sible while accomplishing efficient and safe logging operations. In tractor logging of a shelterwood, for example, it is desirable to use the same skid trails in all entries to limit soil compaction and minimize damage to regeneration. Thus, the skidding pattern developed for the regeneration cut must also fit overstory removal. The logging planner must work with the silviculturist to develop a skid trail pattern that can be used effectively for both entries. An experienced logging specialist working ahead of the operation can consider a variety of alternatives and arrive at an optimum pattern for each site. These kinds of considerations may seem rather small and insignificant when viewed individually, but if they are not taken care of in the planning stage they can lead to serious reforestation problems.

Table 9-4. Percentage of harvest area covered by skid trails using the parallel pattern (based on 10-ft-wide trails).

Skid trail spacing (ft)	*Area in skid trails (%)* [1]
75	13.3
100	10.0
150	6.7
200	5
250	4

[1] $\text{Percent area in skid trail} = \dfrac{\text{skid trail width}}{\text{skid trail spacing}} \times 100$

For example: $\dfrac{10'}{75'} \times 100 = 13.3\%$

Skid trails may be laid out in several different patterns with varying amounts of disturbed area (Conway 1982). Parallel skid trails form a low-density pattern where felling to lead and winching can be used effectively (Figure 9-8). Parallel trails will vary in how much of the area they cover, depending on their spacing. Table 9-4 shows approximate area coverages for different spacings.

The main problem with parallel skid trails is that most of the region's topography is variable and does not conform to such a rigid geometric arrangement. Terrain features like draws, streams, rock outcroppings, slope variations, and the normal differences in timber concentrations make a precisely parallel pattern unrealistic. If the concept of parallel skid trails is adjusted to allow for stand and terrain variability, a more realistic branching pattern can be developed (Figure 9-9). This pattern's converging trails can generally be situated so that spacing is almost as good as it would be with parallel trails.

Branching skid trails should intersect the main collector trails at angles of 45 degrees at the most, oriented toward the landing (Figure 9-10). Angles wider than this will result in damage to reproduc-

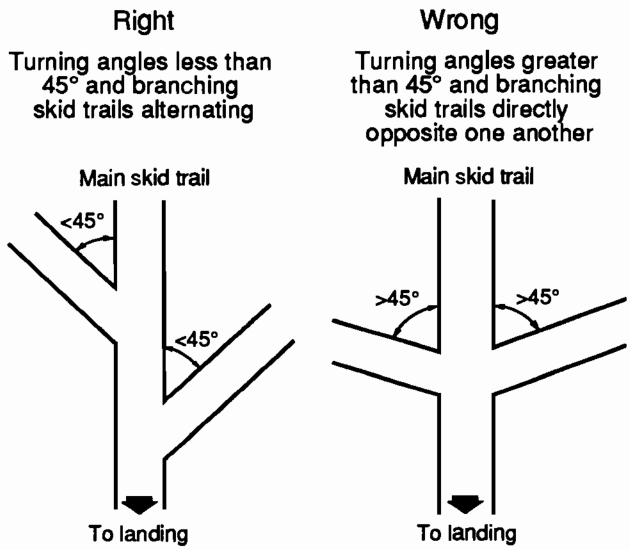

Figure 9-10. Intersections of branching skid trails with main trails.

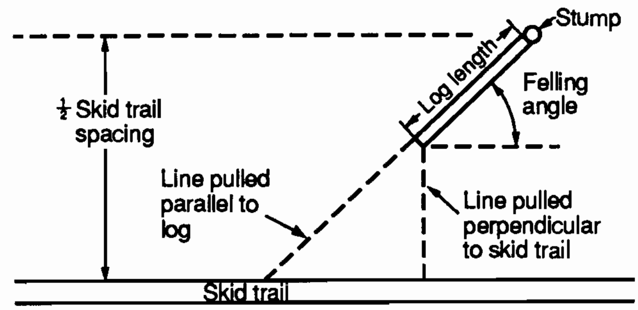

Figure 9-11. Critical variables affecting skid trail spacing.

tion on the inside of the turn when long logs are skidded around corners. Branching trails should be staggered, alternating side-to-side along the main trails (Figure 9-10). Leaving high stumps on the inside curves of trail intersections can help equipment operators turn logs into the main trail without damaging regeneration.

Depending on terrain and timber stand density, skid trails should be kept as straight as possible. Straight trails allow for higher skidding speeds, less equipment positioning time, fewer hangups, and better log control. This does not mean that trails must be perfectly straight. As in any harvesting operation, flexibility and practicality must be considered. Gently curving trails can still provide most of the advantages of straight trails while avoiding obstructions like rock outcroppings, large trees, and dense reproduction.

Skid trail spacing is a function of tree height, felling angle, winching distance, and log length. Skidding equipment is available in a wide variety of winch capacities and line sizes, ranging from 100 to about 500 ft of line. An average winch capacity and line size to use for planning purposes is 200 ft of ¾-inch line. The force required to pull such a line off a freespooling winch allows a single choker setter to pull out about 100 ft of line on flat ground, on the average (Iff 1977). On downhill pulls the distance is somewhat farther, perhaps 150-175 ft. For uphill pulls, the distance is less, about a 50-ft maximum. Skid trails should be spaced so that the optimum winching distance is not exceeded.

Log length is a more critical factor than tree height in the spacing of skid trails (Figure 9-11). For a tree exactly halfway between trails, the length of the butt log is the deciding factor because the top logs will all be closer to the trail. However, tight skid trail spacing in tall timber should be avoided because the top logs of tall trees will fall across the skid trail and be precisely out of lead.

The interaction of these variables is summarized for various combinations in Table 9-5. Spacings given in the table allow for an assumed choker length of 15 ft and stump-jump of 5 ft, since the butt end of the first log will seldom come to rest exactly at the stump.

In general, two skidding vehicles should not be working on the same skid trail. The passing of the machines will cause the trail to be widened, and delays often occur while one machine waits for the other to finish a job. This principle does not apply to a tractor swing operation, where one machine (usually a large tracked vehicle) is used only for winching logs to the trail, while a separate, faster machine (usually a rubber-tired skidder equipped with a grapple) swings logs to the landing. With this technique, the winching tractor starts at the landing and works outward so that the two machines do not have to pass.

Cable systems

From a harvesting viewpoint, saving regeneration on steep terrain where skyline systems are used is generally more difficult than on more gen-

Table 9-5. Interactions of critical variables in determining skid trail spacing.

Felling angle	*Log length (ft)*	*Amount of line pulled (ft)*	*Skid trail spacing (ft)*[1]
30	33.0	50	88
		75	113
		100	138
		150	188
30	16.5	50	72
		75	97
		100	122
		150	266
45	33.0	50	101
		75	136
		100	172
		150	243
60	33.0	50	152
		75	196
		100	239
		150	326
60	16.5	50	124
		75	167
		100	210
		150	297

[1] Calculated from model presented in Figure 9-11 for winch line pulled parallel to the log being winched.

tle terrain. The force of gravity on steep slopes and differences in equipment capabilities make control of timber more difficult with cable systems.

Problems of log control and the area of disturbed ground can both be lessened by locating skyline corridors properly. To the extent possible, corridors should be placed perpendicular to terrain contours. If corridors are at an angle other than 90 degrees, logs will swing downhill, resulting in wider corridors and more ground disturbance (Figure 9-12).

Road systems and landing locations should be laid out to take advantage of terrain features. This will often mean that multiple corridors will converge into one landing location, which will result in a cleared area for some distance below the landing. While this situation may not be desirable, it may be the lesser of two evils. If the alternative, parallel corridors, were used in the same terrain, they would require more landings and probably more roads, taking even more land out of seedling production. Moreover, converging corridors are more efficient operationally because they require less machine rigging time.

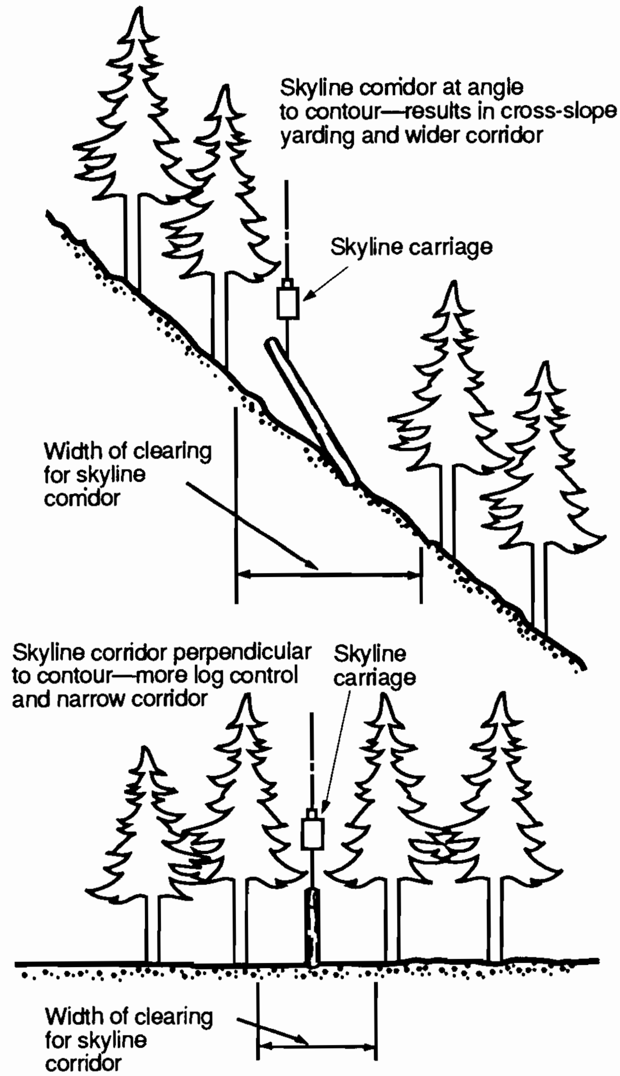

Figure 9-12. Effect of skyline cross slope on width-of-clearing limits for the corridor.

Designating corridors on the ground with flagging before trees are cut is helpful—almost mandatory—in all situations in which a portion of the stand will be retained. This allows the logging supervisor to visualize the harvesting pattern and plan in detail how yarding must proceed. Flagging shows timber fallers where the skyline corridors will be so that they can fell trees in lead to facilitate yarding, protect residual trees, and save reproduction. However, locations of predesignated skyline

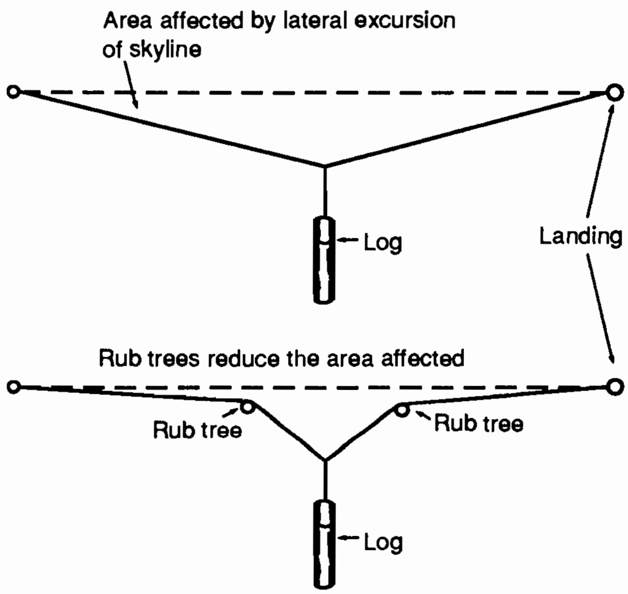

Figure 9-13. Overhead view of rub trees and their effect on lateral excursion of the skyline.

corridors must be somewhat flexible and subject to adjustment once timber is on the ground. Things look different when all the trees to be felled are down, and minor corrections to the yarding pattern may be necessary. A rigid corridor-spacing rule can impose unnecessary restrictions on loggers.

As with skid trails, spacing of skyline corridors depends on the lateral yarding capabilities of the equipment to be used. For most types of manual and mechanical slackpulling carriages used in the region, a reasonable distance that the rigging crew can pull line on a sustained basis is 75 ft to either side of the skyline. A starting point, then, for planning the spacing between parallel corridors is 150 ft. Additional distance can be added if trees are felled to lead. However, to minimize seedling damage to steep ground, lateral yarding distance (and therefore corridor spacing) should be decreased as slope increases.

Deflection of the skyline to one side of the corridor during lateral yarding, a movement called lateral excursion, is necessary for the system to pull logs into the corridor, but it may create unacceptably wide corridors. This means more area in the logging footprint and commensurately more damage to regeneration and residual trees near corridors. Because the skyline will deflect to both sides of its neutral position, corridor width equals twice the lateral excursion distance. While healthy, undamaged seedlings on either side of a 15-ft corridor may constitute a desirably spaced young stand, seedlings on either side of a 30-ft corridor may not. To limit lateral excursion, residual trees adjacent to the corridors can be used as "rub trees" during lateral inhaul (Figure 9-13). Rub trees on a particular corridor can be cut at the completion of yarding and yarded to the landing before equipment is moved to the next setting, or they can be felled toward adjacent skyline corridors and yarded to the next corridor.

Rub trees take extra planning to work properly. Approximate corridor locations must be designated prior to felling, and timber cutters must know which trees to leave. Location of rub trees will depend on timber concentrations in lateral yarding areas and on characteristics of the terrain in the harvesting area (Figure 9-14). If rub trees are left in areas where the skyline is quite high above the ground, the line may be rubbing in the tops of the trees, knocking out branches and creating a safety hazard for the rigging crew. The skyline may even be pulled over the top of a rub tree and come down on the wrong side, causing hangups during yarding and possibly widening the corridor.

Even if it is not certain in the planning stage whether rub trees will be useful, extra trees can be left near the corridor just in case. If they prove to be unnecessary, they can be felled and yarded during the regular progression of the operation.

HARVESTING OPERATIONS

Ground-based Systems

The proper felling method to be used with designated skid trails in ground-based harvesting operations is called felling to lead. Trees are felled in a direction parallel to, or in lead with, the direction in which they will be winched to the skid trails. Trees can be felled toward or away from skid trails depending on their natural lean and the characteristics of the terrain. Trees are felled at an angle of 30-45 degrees from the skid trail, with either butt or top end in line with the direction of winching (Figure 9-15). When trees are felled out of

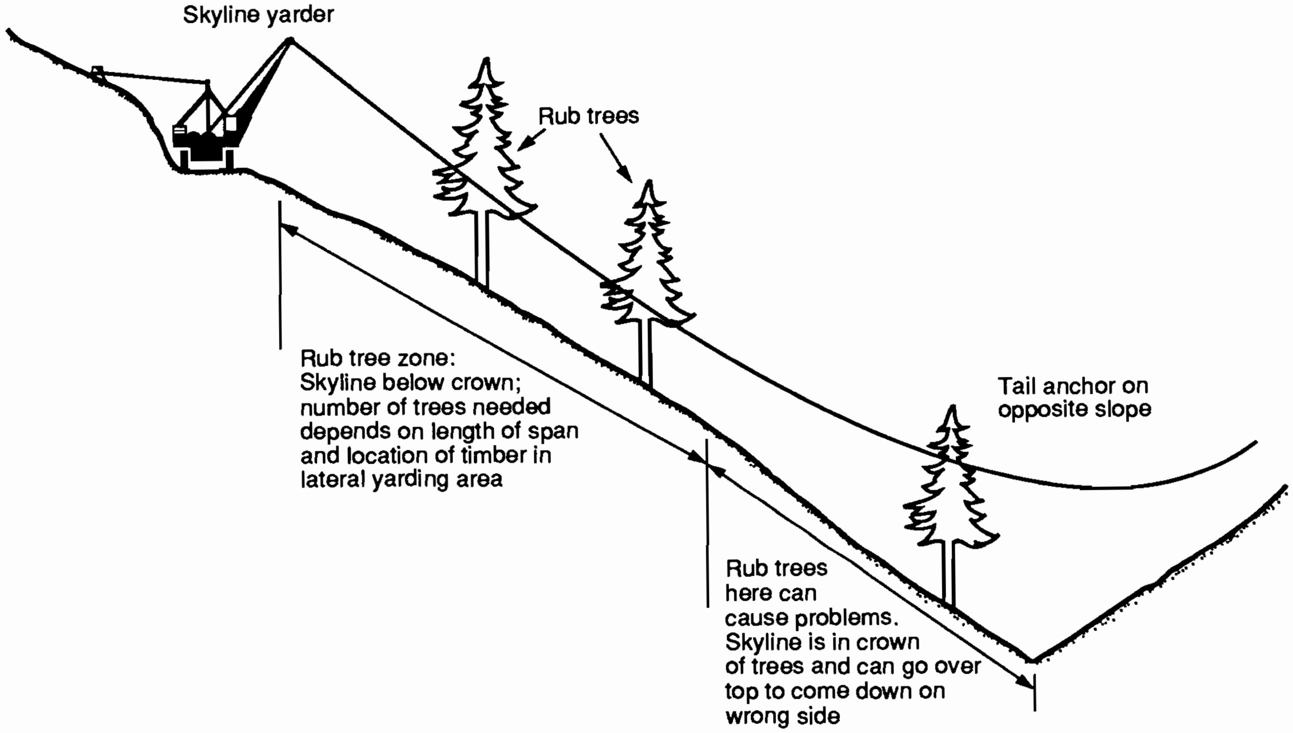

Figure 9-14. Location of rub trees along the skyline profile.

lead, logs must be turned as they are winched toward the tractor, increasing the probability of damage to seedlings and residual trees and often causing logs to hang up or break during winching. Trees immediately adjacent to skid trails are felled parallel to the trail rather than out into the residual stand. Trees that are in the skid trails should be felled and skidded before cutting other timber (if possible); otherwise, fallers may have trouble finding the trails and felling trees to lead (Aho et al. 1983).

In stands with heavy volume and a particularly valuable understory, stage felling and yarding can help save regeneration (Barrett et al. 1976). In this technique, only a portion of the canopy trees are felled, bucked, and skidded at one time. Remaining trees are then felled, bucked, and skidded in one or more subsequent stages, using the areas already disturbed in the first stage. The decisions of how much volume to take in each stage and how many stages to use depend on total volume to be har-

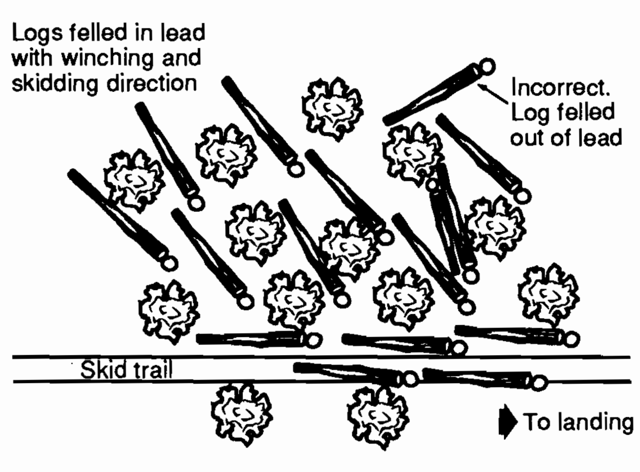

Figure 9-15. Proper tree placement in felling to lead.

vested, number of residual overstory trees, and value of seedlings in the understory. A rule of thumb for stage-felling operations on tractor-harvested areas calls for removing about 40 percent of the overstory in the first stage to open up enough area to get the remaining 60 percent on the ground in one more stage while leaving an adequately stocked understory.

Cable Systems

Herringbone felling patterns have been proposed as the best way to minimize damage to regeneration during overstory removal with skyline systems (Studier and Binkley 1974). If harvesting conditions are ideal, this is theoretically true, but successful use of a herringbone pattern depends on skyline corridors that do not deviate from their planned locations. When corridor locations shift slightly after all the timber is down—a common occurrence—trees felled in a herringbone pattern may actually be in the worst possible position. If the trees are across the corridor rather than in lead with the direction of yarding, logs will have to be turned before they can be pulled into the corridor (Figure 9-16), and seedlings in their path are subject to damage. It is advisable to allow cutters, logging managers, and sale administrators the flexibility to determine the best pattern or combination of patterns.

Felling timber parallel to the terrain contour seems to be the best method to use in saving regeneration. With this type of felling, turning logs during lateral yarding is minimized and location of the corridor is not as critical, especially if corridors are laid out perpendicular to the contour. On very steep terrain, however, parallel felling may result in logs rolling downhill when bucked; some degree of uphill lead may be necessary to hold them on the slope.

Mechanically assisted directional felling—a set of techniques employing mechanical means to control the direction in which a tree falls—may be necessary to achieve the desired felling pattern. Studies of benefits realized from mechanically assisted directional felling have concentrated on reduction of breakage (Hunt and Henley 1981), but these techniques have also been observed to help in saving regeneration (Aho et al. 1983). Tree lining is quite expensive because an auxiliary yarder must be on the site during all felling operations and each tree must be climbed so that a pulling line may be attached. Tree jacking is less costly and usually provides the control needed to fell trees in the desired direction. Tree jacking can be helpful in tractor-logged areas as well as on steeper terrain.

Stage felling is more difficult in skyline logging than in ground-based logging because all operating lines must be taken down after yarding is finished and re-rigged after the next stage is felled. Unless the yarder is used on another site while fallers are working, it is inactive during this time. Moreover, stage felling has yet to prove effective in saving regeneration on steep terrain (J.W. Mann, personal communication, 1990; data on file at Forest Research Laboratory, Oregon State University). However, this technique should not be abandoned in cable logging without more research into its effects on stocking levels, distribution of understory trees, operational costs, and other variables.

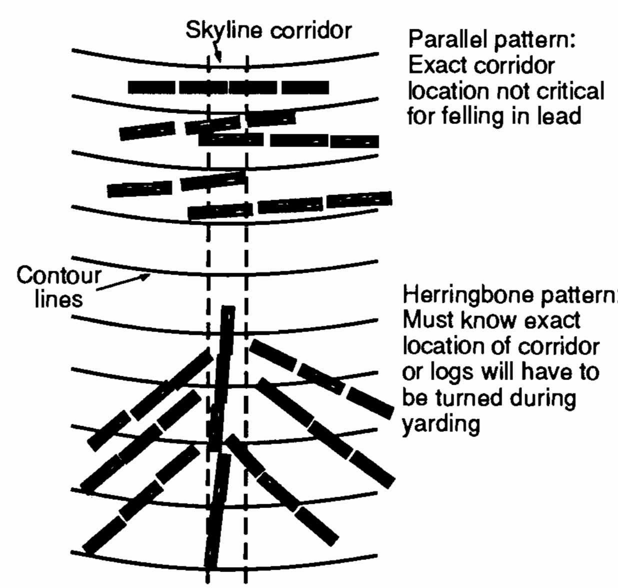

Figure 9-16. Timber felling patterns used in skyline logging to save regeneration and facilitate yarding.

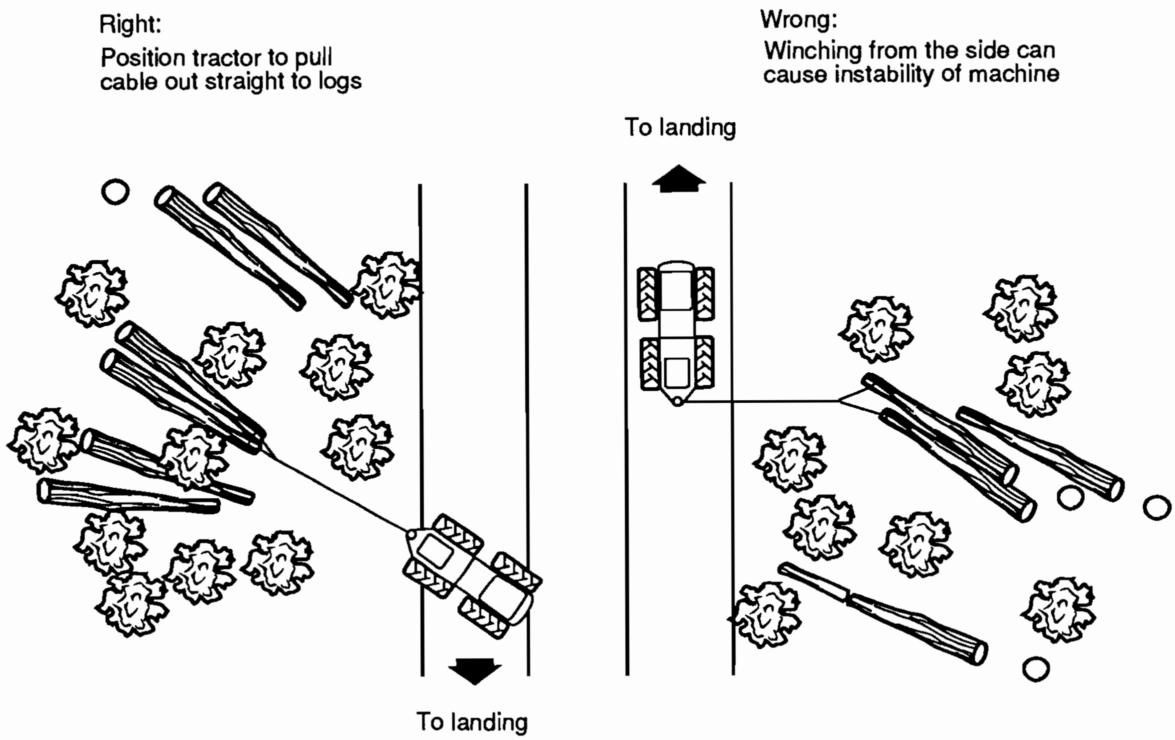

Figure 9-17. Winching procedures in ground-based logging operations.

MINIMIZING DAMAGE TO THE RESIDUAL STAND

Protecting residual trees during harvesting operations continues to be an important problem associated with shelterwood or uneven-aged regeneration methods, particularly on steep terrain where skyline or aerial logging systems must be used. Several studies have addressed this issue (Mann and Tesch 1985, Tesch et al. 1986a and 1986b; J.W. Mann and J. Kraemer, personal communication; FIR report 8(3)2-4, 1986). Even though many of the practices reported in the literature have not been tested in replicated experiments, they have been observed to be helpful in saving reproduction (Mann 1985a). These practices are the ones most often recommended by logging specialists and silviculturists who have experience with the problem. In considering any of them, however, planners should recognize the important tradeoff between maximizing yarding production and minimizing damage. Generally speaking, any special effort to prevent damage to overstory trees or regeneration will increase project costs, from plan preparation through the actual harvesting operation. The value of reproduction must be balanced against the increases in operating costs.

Ground-based Systems

While skid trails should be kept narrow, they must be wide enough to allow for proper positioning of equipment during winching. The winch line should be pulled straight out from the back of the tractor (Figure 9-17). Winching at an angle to the direction of tractor travel may cause the machine to become unstable, especially on steeper ground. Angled winching may also cause logs to swing as they start to move, thus disturbing more ground and potentially damaging nearby trees. Skid trails, therefore, must be slightly wider than the skidding machines to allow for machine positioning.

The pulling force of the winch line is the only means of control that machine operators have over logs during winching. If logs encounter an obstruction or are headed for a patch of regeneration that should be saved, the primary way to change log direction is to move the winching tractor. Good felling techniques and careful initial positioning of winching machines will reduce the need for moving equipment once winching has begun.

Elevating the leading end of the log during tractor skidding can help it follow a straight path, and also eliminates the plowing effect that results from its being dragged flush with the ground. Log elevation is accomplished with integral skidding arches mounted at the rear of the machine. Such arches should be required on logging tractors where protection of trees or regeneration is an objective.

The practice of designating skid trails (Froehlich et al. 1981), useful for minimizing soil compaction on a site, has also been shown effective in reducing damage to residual trees (Aho et al. 1983, Brown and Perry 1984). Designated skid trails are discussed in greater detail below, in the section on maintaining site productivity.

Cable Systems

As slopes increase beyond 35 percent, log control during felling, bucking, and yarding becomes increasingly difficult (Tesch and Mann 1991). Felled trees and bucked logs roll downhill on steep slopes, and cable yarding systems cannot control log movement during yarding as well as tractors can. A likely result is more area disturbed and greater damage to the residual overstory trees and to regeneration, especially during lateral yarding. On slopes greater than 65 percent, controlling log movement is extremely difficult, and the decision to use non-clearcut regeneration methods must be made cautiously. No matter what logging techniques are used, there is a physical limit to what can be done to control log movement on slopes greater than 65 percent (Lindsay 1985). Using mechanically assisted directional felling to fell trees uphill may help hold logs in place.

Downhill skyline logging should usually be avoided except perhaps in clearcuts. Unless logs are completely suspended, they tend to roll ahead of the carriage on slopes greater than 65 percent, flopping to one side or the other of the skyline corridor and disturbing a larger area.

Extremely long skyline spans (in excess of 2,000 ft) may cause more damage to seedlings and residual overstory trees than short spans (Fieber et al. 1982). Yarding low volumes per acre over such long distances may also prove uneconomical; helicopters may be more satisfactory than cable systems in such situations.

Movement of logs laterally to a skyline corridor is controlled mechanically through the carriage. A skyline carriage used with shelterwood or uneven-aged regeneration methods must meet two basic requirements:

1. It must be capable of pulling slack—that is, it must allow the dropline, or the line that extends down from the carriage to the logs, to be pulled out to the side of the corridor by the choker setters to reach logs between corridors. Non-slack-pulling carriages are limited to yarding only within reach of one choker length on either side of the skyline. The longest length a choker can reach and still be managed efficiently is roughly 40 ft, which limits the corridor spacing to 80 ft. This is typically unacceptably close.
2. It must be capable of maintaining a fixed position on the skyline during lateral inhaul. A carriage may be made stationary by a clamp that holds it to the skyline, an operating line (like the haulback) that is secured to the back of the carriage, or simply by its own weight. If the carriage is not stationary during this phase, it will creep up toward the yarder (as tension increases in the dropline) when logs are being pulled in from the side, and logs being laterally yarded could damage seedlings or residual trees as they follow the carriage upslope.

In some cases it may be desirable to move the carriage during lateral inhaul. If a log rolls downhill, becomes hung up on a stump or other obstruction, or is carrying a large amount of slash as it moves toward the corridor, a change in direction is necessary. Moving the carriage up or down the skyline will change the direction of pull and thus the track of the log (Figure 9-18). It is usually better to move the carriage uphill in this case because a downhill move will put slack in the

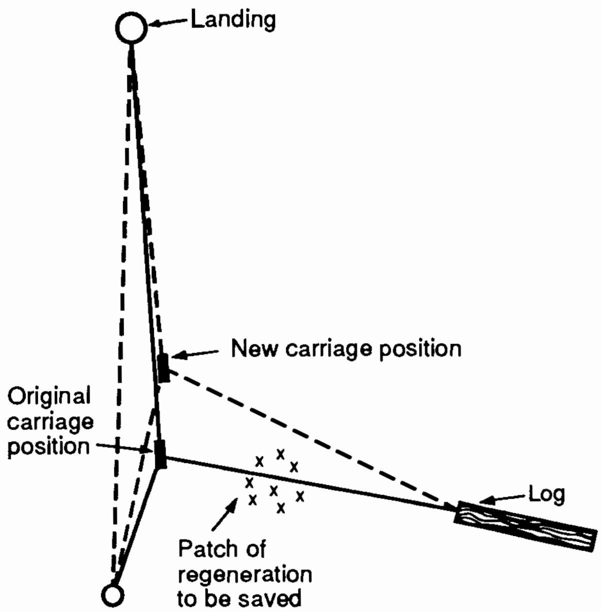

Figure 9-18. Moving the skyline carriage during lateral inhaul to avoid an obstacle or area of dense reproduction.

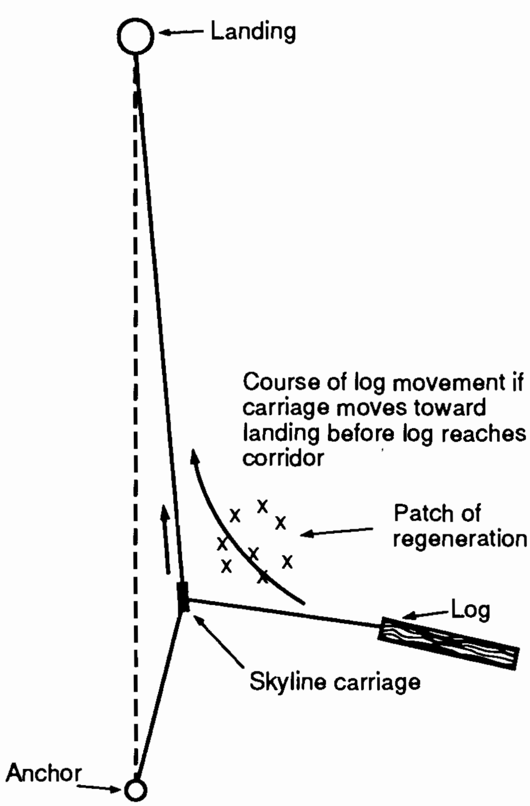

Figure 9-19. Increased seedling damage associated with beginning carriage movement before lateral yarding is complete.

dropline, resulting in the log's rolling or sliding downhill. It should be noted that not all carriages can be moved while the dropline is out—many are clamped to the skyline until the logs reach the carriage.

Logs should be brought as far into the corridor as possible (unless they are fully suspended) before starting carriage movement to the landing. If the carriage begins to move before logs are all the way in, the area through which they will turn is greatly increased and more damage could occur (Figure 9-19). The rigging slinger (the person in charge of properly getting the logs into the corridor) may sometimes signal for carriage inhaul before the logs have reached the corridor as a means of speeding up production. This practice should be avoided when minimizing damage is important. Lateral inhaul and inhaul to the landing should be separate elements of the yarding cycle.

Sufficient deflection and carriage clearance are mandatory if logs are to be controlled during lateral yarding. In general, the higher the carriage, the greater the lift exerted during lateral inhaul, and the greater the control afforded over gravitational forces on the log. More control means less damage to regeneration (Gaas 1974, Burditt 1982, Fieber et al. 1982). Depending on the terrain and the line capacity of the yarder, deflection and carriage clearance are obtained by rigging the outer skyline anchor (the tailhold) across a draw on a slope facing the area to be yarded, or by rigging a lift tree or a tail spar (Figure 9-20). Lift trees can be very important in saving regeneration, especially when logs are being yarded close to the tailhold. If the skyline were anchored directly to a stump on a continuous slope, the carriage would be quite close to the ground at the outer end of the skyline corridor, which could cause much damage to nearby reproduction. On continuous slopes, a lift tree is the only practical way to obtain deflection with a single-span skyline system. Trees to be used as logging spars or lift trees must be designated in advance of felling.

In terrain with convex slopes, extremely long continuous slopes, or broken ground, it may be difficult to get enough deflection with a single-span skyline. In these situations, a multi-span skyline should be considered. Multi-span skylines have intermediate supports to keep the skyline and carriage elevated well above the ground (Mann 1984).

The skyline should not, however, be suspended in or above the tops of leave trees in the first entry. When the skyline is this high, excessive top damage is likely (Fieber et al. 1982). Planners must realize that keeping the skyline and carriage below the branches of overstory trees also means that full suspension of logs is not feasible. An exception must be made, of course, when full suspension is mandated, as over stream buffer strips.

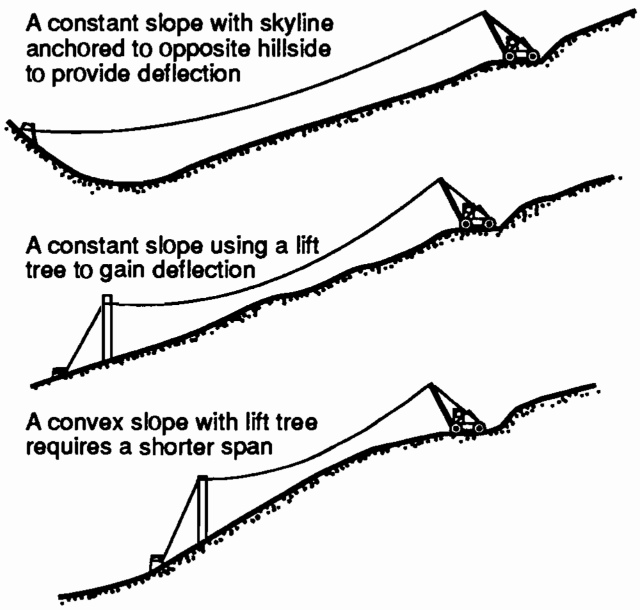

Figure 9-20. Single-span skyline conditions and methods for obtaining deflection and carriage clearance. Adapted from Studier and Binkley (1974).

SITE PREPARATION AND PLANTING

Although site preparation and planting are not usually addressed as harvesting concerns, some consideration should be given to them in the context of harvesting. As we have noted before, the steps taken to implement any regeneration method are not discrete but interrelated. Harvesting can affect the ease or difficulty of subsequent site-preparation and regeneration efforts.

With the shelterwood method, to the greatest extent possible, logging slash should be disposed of and the site prepared for regeneration between the first (regeneration) cut and removal of the residual trees. Ideally, slash should be burned or otherwise thoroughly removed so that it will not have to be dealt with after the second entry, when additional seedling damage might result.

Some site preparation can be accomplished by harvesting operations, depending on the degree of ground disturbance desired and the harvesting system used. Planners should consider the site-preparation capabilities of the various types of harvesting machinery (Chapter 10).

If artificial regeneration is planned, seedlings should be planted where they will likely be protected from subsequent logging damage. For tractor-logged areas, the most effective planting area is on the landing side of a stump from a tree that was cut during the first entry. Around remaining trees, the planting location least likely to be disturbed during overstory removal is the side away from the skid trail. In areas to be logged with a skyline, the downhill side of stumps and overstory trees should be used as planting sites. Planting is covered more thoroughly in Chapter 14.

MAINTAINING SITE PRODUCTIVITY

Maintaining the quality of the site is one of the greatest concerns involved in coordinating harvesting operations with reforestation requirements. Soil disturbance, particularly soil compaction, is the chief concern. Soil compaction is one measure used to describe the overall condition of a forest site after machine operations. Soil displacement and other disturbance may also result from the same machinery activity (Dyrness 1965), and these are also indicators of site condition. Some clay soils may remain compacted for 30 years or more, while others, especially sandy soils in areas of yearly freezing and thawing, may recover in only 3 years (Holman et al. 1978).

The use of designated skid trails (Froehlich et al. 1981) may be the most effective way to avoid excessive compaction of soils. These have been used operationally in southwestern Oregon and northern California. In this practice, harvesting equipment is restricted to operating only on pre-marked travelways. In operations where skid trails are not designated, as much as 50 percent of the harvested area is typically covered (Froehlich 1977). Skid trail coverage can be reduced to around 10 percent with proper planning and layout (Table 9-4), depending on the skidding pattern used and how far the winch line is pulled. Some research has shown that using designated skid trails sometimes increases logging costs (Bradshaw 1979), while other experiments record no increase or even a reduction in costs (Froehlich et al. 1981, Tesch and Lysne 1986).

Strategies to manage soil compaction should involve all machinery, not only that used for harvesting. In particular, equipment used for site preparation and fuels management should be deployed as efficiently as possible. The anticipated benefits from logging with cable systems or using designated skid trails can easily be negated by indiscriminate use of machines in site preparation and slash piling. However, it may be possible to minimize machine coverage by combining some elements of site preparation into the harvesting job.

HARVESTING CONSIDERATIONS IN UNEVEN-AGED AND ALTERNATIVE SILVICULTURE

At present, there is little experience or research on which to base recommendations for harvesting in uneven-aged management situations or in the cutting prescriptions of alternative silvicultural methods (Franklin 1989), with their emphasis on heavy conifer retention. Most uneven-aged management on west-side forests has occurred on small, private tracts. Managing forests by alternative silvicultural methods to avoid clear-cutting and improve forest biodiversity is still in the proof-of-concept stage and, in our opinion, is not ready for large-scale implementation until many operational questions have been answered. However, information from other, more traditional harvesting operations can be used to hypothesize what might happen when these proposed approaches to forest management are taken.

No matter what the harvesting system or leave-tree arrangement used in overstory retention systems, the cost of harvesting and other stand management activities will be increased, sometimes greatly increased, over those of more traditional clear-cutting techniques. Kellogg et al. (1991) showed a 23-percent increase in cost of implementing a two-storied stand development over the cost of clear-cutting, and a 25-percent increase in the cost of implementing a group selection harvest prescription over the cost of clear-cutting. The volume left in standing trees and in windfall that cannot be efficiently recovered represents lost revenue, and the inevitable damage to residual trees during harvesting and site preparation results in decreased future yields. Depending on the leave-tree pattern selected, managers may also have to deal with decreased timber yields, disease passed from overstory to new regeneration (for example, mistletoe), and brush competition problems as understory vegetation is exposed to light. Another critical issue in any uneven-age management scheme is safety; residual trees present certain dangers to fallers and other workers. Costs of these problems must be balanced against potential gains in increased structural and biological diversity promised by alternative silvicultural methods.

Uneven-aged management will often result in the removal of only a few trees per acre in an entry, with periodic entries scheduled at some predetermined interval. Alternative silvicultural proposals are currently somewhat unspecific and difficult to interpret, but their rationale is to provide a mixture of species, variations in ages and sizes of trees, clusters of snags, and wooded riparian areas in future stands. A prevalent alternative silviculture prescription in this region would leave 6-12 green trees per acre as well as standing snags. Such a prescription is similar to that used in the regeneration stage of traditional two-stage shelterwood management, but it differs in that no overstory removal is planned—residual large trees will be retained throughout the next rotation and perhaps beyond.

The elements of planning and implementation that pertain to any kind of non-clearcut harvesting discussed previously in this chapter can be applied judiciously to uneven-aged and alternative cutting prescriptions. Some ideas on specific planning and operating strategies follow.

Gentle terrain—Use designated skid trails that will become a permanent part of the forest transportation system. Problems associated with this include locating and maintaining trails on large areas as well as damage to residual trees during potentially frequent entries. The initial location, mapping, and permanent marking of skid trails on large areas of forest land is a task that will require increased manpower. If restriction of skidding equipment to designated skid trails is not strictly enforced, soil compaction and site degradation could become major problems. Diligent administrative oversight is essential.

Steep terrain: cable logging systems—Cable systems may or may not prove to be of use in uneven-aged management areas where frequent entries will be made to harvest a few trees per acre. The expense of preparing landing areas, cutting skyline corridors, and moving and rigging the cable equipment for this kind of selective logging would, in most cases, be high and might cause more visual site disturbance than desirable. However, large-scale cable systems are very flexible. Given the generally higher value of selective-cutting contracts, cable systems may become a viable alternative. Also, small swing-boom cable cranes that can operate from small landings with only two or three guylines will likely be useful in salvage logging and selective cutting of green trees within 1,000 ft of established roads.

Skyline systems will be quite useful in New Forestry applications, just as they have proven to be with the shelterwood method on steep terrain. Skyline harvesting techniques discussed previously can be applied to this type of management as well, with the added consideration that large leave trees will have to be strategically located for efficiency and safety and to limit damage to the trees.

Leave-tree patterns that should be tested include systematically placed "spokes," wedge-shaped areas radiating out from landings, and clusters, representing some predetermined percentage of the harvest area (Figure 9-7). Any of these patterns could help provide the values intended by alternative silviculture proposals. In marking leave trees, consideration should be given to factors that will (1) facilitate future harvesting entries without excessive damage to regeneration in the event of blowdown, (2) permit broadcast burning to reduce fire hazard, (3) permit safe and effective application of chemicals in the event that conifer release is necessary, and (4) provide an aesthetically pleasing landscape.

Steep or gentle terrain: aerial systems—Aerial logging with a variety of different-sized machines may be the only practical way to harvest timber from uneven-aged or alternatively managed stands in difficult terrain. Aerial systems have two advantages over the others: their yarding distance is not physically restricted and they do not rely on high volumes per unit area for economical production. Flight speeds of 90 mph and vertical lift of the logs make helicopter logging almost independent of most of the variables that affect costs and production rates of other harvesting systems. An exception is the time involved in moving ground workers relatively long distances from tree to tree for felling, bucking, and hooking.

SUMMARY

Timber harvesting, reforestation, and silviculture go hand in hand. Harvesting is the major silvicultural tool used to manipulate forest vegetation to achieve a variety of management goals. This chapter deals with capabilities, limitations, costs, and impacts of harvesting systems. In particular, it discusses how these systems interact with reforestation activities. Strong consideration is given to describing the "logging footprint," or characteristics left behind in the forest after logging operations. Choosing a timber harvesting system and setting the standards of quality control to be exercised over operations are probably the most important decisions made by forest managers, because they determine the "logging footprint." This footprint can be managed to help achieve successful

reforestation and to minimize or eliminate the negative effects of harvesting on regeneration, residual trees, and soil. This chapter focuses on the techniques for such management, particularly in regeneration methods calling for retention of some part of the stand.

Three harvesting systems are common in the region: ground-based, cable, and aerial systems. Ground-based systems, usually the least expensive of the three, are best suited to gentler slopes. Their main environmental drawback is their potential to cause compaction of the soil. Designated skid trails concentrate impacts of machinery onto a small percentage of the harvest area, and thus help reduce the extent of soil compaction and associated seedling growth losses.

Generally, cable systems disturb the site less than ground-based systems and are thus well suited to harvesting operations where overstory trees or seedlings are to be retained. Cable logging tends to be more expensive than ground-based logging.

Aerial logging is usually the most expensive of the three, but it causes the least disturbance to the ground and to residual trees or seedlings, giving it an advantage in situations where environmental or aesthetic concerns predominate.

Each system has benefits and limitations that apply at every stage of a harvest operation. Before choosing a system for a given job, planners should consider size of the timber, characteristics of the terrain, time of year the harvest will be conducted, and amount and distribution of trees and seedlings to be retained. In addition, such management considerations as placement of skid trails, skyline corridors, spars, landings, and haul roads, as well as economic constraints on equipment and personnel, should be well thought out.

In ground-based harvesting, skid trail patterns should be designed with future entries in mind. A branching pattern of more or less straight trails with relatively narrow-angled intersections is recommended. In cable systems, skyline corridors should be placed perpendicular to the terrain contour so that logs are easier to control as they are yarded. Two patterns exist: a converging pattern, with several corridors meeting at a single landing, and a parallel pattern. The one that best matches the terrain should be selected. Both skid trails and skyline corridors should be flagged prior to harvest.

Trees should be felled in lead with skid trails in ground-based operations, and generally parallel to the terrain contour in cable systems; some uphill lead may be necessary on steeper slopes. Mechanically assisted directional felling is helpful in controlling direction of fall.

Additional techniques to minimize damage to regeneration in ground-based logging include keeping the winching line straight out from the back of the tractor and raising the leading end of the log. In cable systems, such techniques include avoiding downhill yarding on steep slopes, using intermediate supports or tail spars to achieve greater deflection, bringing logs fully into the corridor before yarding, designating rub trees to limit lateral excursion of the skyline, and fully suspending the load in some situations.

There is little research or experience on which to base harvesting recommendations for the concepts proposed under the title of "New Forestry." Such concepts are certain to be more costly to implement, and they will require more care in layout. Information from traditional harvesting systems can be extrapolated with care to hypothesize results from such approaches.

In sum, emphasis should be placed on the harvest planning process: decisions that must be made, their hierarchy and sequencing, information required, and how harvesting decisions support reforestation and overall forest management goals. Harvesting systems are evaluated on basic physical, economic, and operational criteria, but attention should also be given to the myriad of operational quality-control considerations that, in aggregate, determine success or failure.

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