How might existing and new technologies influence forest operations and the resultant conditions of forests?

Chapter 15: Forest Operations Technology

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Key Findings

- A wide range of technology is available for forest management in the South.
- New technology makes forest operations more productive, cost-effective, and environmentally sensitive.
- Increases in forest operations productivity and the logging workforce are being used to meet the increasing demand for fiber and to reduce unit production costs.
- Southern forests are generally managed under economic constraints. Choices of rotation length, systems, and operations technology are fundamentally determined by the costs and values of a selected management regime.

Introduction

Forest operations include regeneration harvests, thinning, pruning, timber stand improvement, site preparation, planting, prescribed fire, vegetation control, and fertilization. The methods, materials, and systems used to transform the forest are the technology of forest operations.

Forest operations are designed to meet management needs. For example, ecological requirements for natural regeneration in a particular forest type may include certain light levels, soil conditions, and seed-source spacing. These ecological requirements translate into the prescription for the forest operation. For example, the stand must be opened up to a certain density; stems must be selectively removed based on size, species, and spacing; and the soil litter layer should be disturbed for seed catch, but not compacted. These requirements define the technology that is needed to meet management objectives. Forest operations technology is also shaped by the requirements of forest industry. Product form from the woods must be compatible with the handling equipment at the receiving mill. Minimum specifications, such as small-end diameter, define the way trees are cut to length. Developments in forest products transportation, mill processes, and products affect the requirements of forest operations. Changes in the forest products industry may lead to new constraints or opportunities for work in the woods.

Available technology defines the possibilities of forest management and forest products by limiting the feasibility of operations. Generally, forest operations are limited by terrain, piece size, productivity, or costs. Increased effort (longer distances, handling more pieces, steep slopes, wetter ground) translates into greater cost per unit of production or per acre. The fundamental question facing the forest manager is whether the prescribed operation is both technically and economically feasible.

The current condition of southern forests, in part, reflects forest operations technology of the past. The mosaic of managed and unmanaged forested areas is partially a result of the technical and economical limits of previous forest operations. The network of roads and skidtrails on the forested landscape resulted in part from limitations on extraction distance and terrain. Stand composition of regenerated acres reflects the past site preparation and stand establishment techniques. Similarly, future landscapes of southern forests will be an expression of the capabilities and limitations of today's technology. Understanding the role of technology in shaping forest conditions will help predict the future of the southern forest resource.

This chapter documents current southern forest operations and describes the interaction among forest operations technology, management practices, and forest condition.

Methods

Descriptive data in this chapter were generally obtained through standard literature review methods. The evaluation of logging workforce productivity, however, involved some additional data analysis. County-level employment data from the 1990 Census were merged with 1995 county-level timber products output data. Total logging employment was assumed to be relatively constant from 1990 to 1995 based on employment data from the Annual Survey of Manufactures (ASM). Timber product output in thousand cubic feet and logging employment were aggregated by ecological section. Annual productivity per logger was calculated at the ecological section level. The geographic distribution of logging workers was examined by combining county-level logging employment with total county land area to arrive at logging workers per 100 square miles. Finally, analysis of variance was used to examine variation in aggregate logging productivity as a function of percent pulpwood and percent hardwood in the section.

Data Sources

While most of the information for this chapter is derived from conventional literature sources, online databases were utilized to estimate workforce and productivity. The primary source of county-level timber product output (TPO) data was the Forest Inventory and Analysis (FIA) TPO Database Retrieval System (Anonymous 2000). This database contains information about roundwood products harvested in each county for calendar year 1996, by species and product class.

There are several sources of logging employment data. County-level data were obtained from civilian labor force data of the 1990 decennial census (U.S. Census Bureau 2000b), the most recent available sample of self-reported employment status. A sample of 1990 Census respondents described their industry and occupation. Based on this information, people were assigned to standard occupational and industry codes. Total logging employment was assumed to consist of both occupations 496 (Timber cutting and logging) and 494 (Supervisors, forestry, and logging). State-level logging employment data for the period 1997 to 1999 were derived from the Covered Employment and Wages Program (ES-202) of the Bureau of Labor Statistics (U.S. Department of Labor, Bureau of Labor Statistics 2000a). The ES-202 data are a 100-percent report for all establishments covered by unemployment compensation insurance. Older state-level workforce data were compiled from the ASM (U.S. Census Bureau 2000a). ASM data are collected through a mail survey of a sample of establishments. Both the ES-202 and ASM were queried for total state-level employment in Standard Industrial Classification (SIC) Code 241, Logging. Some years of the ASM data are missing for Kentucky, Tennessee, and Oklahoma.

The 1990 Census provides a snapshot of logging employment at the county level. Because it is based on self-reported occupation, it may provide a more accurate measure of workforce in an industry with many small firms and self-employed workers. However, it is also subject to errors in classification, and some nonloggers are likely included in the 494/496 occupational codes. The annual data from the ES-202 and ASM surveys provide an employment time series, but likely underestimate the logging workforce because they are based on a sampling of establishments. A comparison of the 1990 workforce at the county and state-level highlights the possible disparity. The ASM data estimate a total southern (less Kentucky, Tennessee, and Oklahoma) logging workforce of 36,000. In comparison, the decennial census estimates a total of 44,066. Most States are within several hundred workers. Texas, Virginia, and Mississippi, however, account for 6,000 of the 8,066 difference in workforce estimates. For this report, the decennial census data were considered a reasonable estimate of workforce and the manufacturer survey data were used to model trends over time.

Results

Description of Forest Operations Technology

Forest management requires a range of tools to implement prescriptions from planting, fertilization, burning, and herbicide application, through thinning and product extraction. International Standard 6814 (ISO 1999) provides common definitions for individual machines. In many management activities, however, the individual machines are grouped into systems. A forest operation system is more than technology represented in equipment design. A system includes the technology of methods and human work. While the capabilities of individual machines are of interest, the overall productivity and impacts of operations are the result of the cumulative effect of systems.

Technology for site preparation and establishment—Site preparation and stand establish-ment operations may require seedbed preparation, reduction of competition, alteration of soil moisture or physical properties, or nutrient amendment.
The desired management objectives are to control stocking, species composition, survival, or growth. Given the wide range of sites and objectives in the South, there are many operations that can be employed. Since 1952, a periodic survey of southern forest land managers has been conducted to estimate the prevalence and costs of forest management practices (Dubois and others 2001). Fifty-four percent of the responses to the most recent edition of the "Cost Trend Survey" were from forest industry, 32 percent from consultants, and 14 percent from public agencies.

Prescribed fire is the least expensive way to prepare the forest floor for regeneration. It provides some control of herbaceous competition, exposes mineral soil for seed catch, and reduces logging debris. Prescribed fire is used in prescriptions for natural regeneration by the seed-tree, single-tree selection, and shelterwood systems, as well as for artificial regeneration. Waldrop (1997), for example, describes the use of manual felling combined with fire to regenerate pine-hardwood stands in the Southern Appalachians. Fire often controls hardwood growth enough to allow pines to become established. While regeneration is an important use of fire, the "Cost Trends Survey" found the most common use of fire (about one-third of treated acres) is to reduce hazardous accumulations of fuels at mid-rotation.

Like prescribed fire, chemical treatment is used to control vegetative competition for light, moisture, and nutrients. Forestry herbicides can be applied by stem injection, soil application, or foliar spray. Busby and others (1998) compared herbicide treatment at stand establishment with early release applications and found that herbicide application at stand establishment had the greatest economic returns. Groninger and others (1998) describe the effectiveness of herbicide injection for precommercial thinning of oak stump sprouts. The "Cost Trends Survey" found that about one-fourth of the treated acres were by aerial application at the time of stand establishment. Another third were chemically treated to achieve early release or herbaceous weed control. The reported costs of herbicide treatment were about four times those for prescribed fire ($68 versus $18 per acre).

Mechanical site preparation is designed to modify soil conditions, clear planting sites, and control

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competing vegetation. Each type of operation addresses specific site conditions. Drum chopping, for example, knocks down standing material and breaks it into pieces using large rolling cylinders fitted with blades. In shearing, an angled blade on the front of a crawler tractor splits stumps, moves debris, and exposes mineral soil. Raking also uses a special blade on a crawler tractor to move and pile slash. Surface soil can be disked to reduce vegetative competition. Bedding loosens and moves soil to create raised planting areas. Finally, subsoiling or ripping fractures heavy or compacted soils. Site preparation prescriptions may call for a single type of treatment or a combination of treatments. According to the "Cost Trends Survey," the most common treatment in the Piedmont is a combination of subsoiling, disking, and bedding accomplished in a single pass with a 3-in-1 plow ($121 per acre). This tool was developed around 1990 to reduce site preparation costs. On the Coastal Plain, a multipass treatment combining shearing, raking, and piling is the most common mechanical treatment, averaging $155 per acre.

About 2 million acres were planted in the South in 1997 (Moulton 1999). The acreage was nearly evenly split between nonindustrial private forest (NIPF) landowners and forest industry. Direct seeding accounted for only 0.4 percent of the total. Nearly 1.3 billion seedlings were produced in southern nurseries, and the average planting density was 618 trees per acre. The "Cost Trend Survey" found that most planting (79 percent) was done by hand rather than by machine. Machine planting is slightly more expensive, averaging $45 per acre compared to $39 per acre for manual work. Machine planting is also more constrained by site conditions, such as debris, slope, and soil moisture. Seedling costs vary considerably, depending on species, genetics, and product form. One source, for example, lists containerized loblolly pine seedlings for $155 per thousand, while similar seedlings in bare-root form are $46 per thousand. Thus, total costs for planting may range from $85 to $200 per acre.

With these significant investments in site preparation, improved seedlings, and planting, fertilization is increasingly common in the South. Almost 1.6 million acres were treated in 1999 (North Carolina State Forest Nutrition Cooperative 1999). Some applications are at stand establishment to promote initial growth, but about two-thirds of the treated acres are in established stands (Jokela and Stearns-Smith 1993). The most common fertilizers are dry solid forms of urea (for nitrogen) or diammonium phosphate (for nitrogen and phosphorus). The "Cost Trends Survey" found that nearly all fertilizer is applied by airplane or helicopter.

Technology for stand management and product recovery—Many prescriptions call for manipulation of vegetation in established stands: thinning, sanitation removals of diseased or infested trees, regeneration cuttings in shelterwood or group-selection systems, and harvest of crop trees. All of these treatments involve some type of felling and, in most cases, processing and extraction. Stokes and Watson (1996) describe a range of systems for plantation thinning, and Stokes (1991) outlines systems used in southern timber harvests. These systems are sometimes defined by the forest product that is produced (pulpwood or sawlog). These distinctions, however, are less definitive today as multiproduct harvesting becomes more common. A more useful description may be the level of mechanization, from animal logging systems to helicopters.

Animal logging was replaced by tractor logging in the 1930s to reduce costs. Yet, 60 years later, animal logging systems are still found in the southern forest as specialty operations. Various surveys indicate a public perception that animal logging is ecologically and visually preferred over more mechanized systems. Toms (1999) described current animal logging systems used in Alabama. In all of these operations, felling, delimbing, and processing are done with chainsaw. Trees are bucked at the stump to log lengths for primary extraction with animals. Most crews take two animals to the woods and work them as singles rather than as a team. Systems vary in extraction and loading. The traditional animal logging crew skids logs to a loading point where a self-loading truck (a side-loader or a big-stick loader) can access the material. Some crews use a front-end loader or knuckleboom to increase productivity. A final variant is a hybrid system that combines animal prebunching with subsequent extraction by a conventional skidder or forwarder.

Production is relatively low with animal logging systems. Toms (1999) found average weekly production ranged from 2,500 cubic feet for the traditional system to 7,000 cubic feet for the hybrid variant. Terrain, skidding distance, crew experience, and degree of mechanization are critical factors affecting the production rate. Uphill skidding or heavy brush can significantly reduce output. To maximize productivity, animal loggers prefer to work in large timber where one-log loads approach full capacity and at short extraction distances. A study in the Missouri Ozarks (Ficklin and others 1997) observed mules operating at skidding distances of 1,050 feet, but Toms and others (1996) found an average skidding distance of less than 200 feet.

The low production rate and minimal move-in costs make animal logging operations most competitive on small harvest units. As long as total harvest volume exceeds several loads, there is little economic penalty associated with small tracts. In fact, the smallest unit reported by Toms (1999) was a 1-acre tract, and the median tract size was only 20 acres.

The primary advantages of animal logging are minimal soil disturbance and residual tree damage, suitability to small tracts and selective cutting, and minimal noise and pollution. Balancing these advantages, however, are the low overall production rate, a significant reduction in productivity with small diameter pieces, stand disturbance associated with loading and woods roads, and the need to minimize skidding distance.

In 1998, an extensive survey of animal logging in Alabama identified 52 contractors mostly operating in the northern half of the State (Toms and others 1998). Assuming an average production of 4,000 cubic feet per week, the total output of animal loggers in Alabama represents less than 0.5 percent of the statewide roundwood harvest in 1995 (Johnson and others 1998).

Mechanizing the extraction function of an animal logging system leads to the manual cable skidder system. In this operation, trees are manually felled, limbed, and topped. A rubber-tired cable skidder pulls logs to a landing for loading. The unique feature of cable skidders is their ability to winch logs. By pulling cable from the skidder to the log, trees may be pulled into a skid trail with little soil disturbance. The winch is also useful on wet sites when the skidder loses traction. By slacking the winch and driving ahead, the load can be pulled through the trouble spot. Cable skidder systems are typically used in broken, steep, or wet terrain, in large-diameter sawtimber, and in selection harvests.

The feller-buncher and grapple-skidder system has significantly increased harvesting productivity. Feller bunchers fell trees with either a saw or shear and then place the trees in bunches for further handling. By accumulating felled trees in piles, the feller buncher makes the subsequent skidding process more productive. Grapple skidders take advantage of the bunched wood by grasping a full load with a large pincer on the back of the machine. Cable skidder operators, in contrast, have to stop and tie a wire rope to each tree. With most feller-buncher systems, the wood is skidded in tree lengths to either a landing or a processing area for delimbing. Gate delimbers are large steel grates that are set in the woods at some distance from the landing. By backing the load of trees through the grate with the skidder, most pine limbs can be broken off. A landing sawyer may be employed to clean up the wood prior to loading. Stroke delimbers, loader-mounted, pull-through delimbers, and flail delimbers (Mooney and others 2000) are gaining acceptance to improve delimbing quality, reduce waste, and eliminate manual chainsaw work. A typical feller-buncher and grapple-skidder system includes one feller buncher, two grapple skidders, a gate delimber, and a knuckleboom log loader. If products are sorted out, higher value products are bucked from the tree-length pieces at the landing either by chainsaw or slasher. These systems find greatest application in even-aged stands with trees of uniform size and high pulpwood volumes.

In-woods chipping is an extension of the feller-buncher and grapple-skidder system. In these operations, a flail-chipper is added at the landing to produce pulp-quality chips from tree-length stems. A spinning chain flail removes bark and limbs, and the clean stem is chipped and blown into a waiting van. Watson and others (1991) found that in-woods chipping produced chips of comparable quality to mill-produced chips. Flail chipping actually left a higher percentage of total tree biomass in the stand (31 percent) compared to conventional tree-length harvesting (24 percent). The system is balanced to the productivity of the chipper. Thus, a typical in-woods chipping operation may require two feller bunchers, three skidders, a loader, and the chipper. High production is necessary to support the cost of the equipment. Munn and others (1998) noted an average production of about 500 tons per day for in-woods chipping. A similar system without the flail debarker may be used to produce fuel chips.

Cut-to-length (CTL) technology produces a different product form at roadside. It is a ground-based system in which felled trees are processed at the stump into defined log lengths. Characteristically, the CTL wood is transported to roadside on a forwarder, a machine that carries rather than drags wood. Forwarders were used years ago in southern shortwood operations. CTL technology has been advanced in Scandinavia, where it is the state-of-the-art system for forest harvesting. Modern harvesters fell trees and process them through computerized harvester heads that delimb and buck trees to optimum product lengths. Eight-wheeled forwarders accumulate, sort, transport, and load wood onto highway trailers. A key advantage of CTL systems is that they process trees in the woods, leaving a layer of limbs and tops on the ground to drive over. This reduces soil disturbance and compaction. Lanford and Stokes (1996) compared a CTL system with a feller-buncher and grapple-skidder system in a pine thinning and found that costs and productivity of the two systems were practically equivalent.

Several specialized systems have been developed for wet sites (Stokes and Rummer 1997). Operations typically incorporate modifications to improve driving on soft soils. Conventional feller bunchers may be adapted by using a wide-tracked feller buncher. Skidders can be equipped with either wide tires or dual tires to reduce ground pressure. Tires up to 72 inches wide may be used. Large-capacity extraction machines have also been developed to reduce the need for roads on wet sites. Clambunk skidders may drag up to three times the load of regular skidders. Tree-length forwarders carry a full truckload of wood supported on 10 wide tires. Both clambunks and tree-length forwarders can be combined with tracked feller bunchers and skidders for felling and short-distance extraction.

Shovel logging is another adaptation for wet sites. Originally developed in the Pacific Northwest, shovel logging was modified in the 1990s for southern conditions. The basic system uses a tracked feller buncher to fell and pile trees. A second tracked machine, the shovel logger, moves felled trees and aligns them into a solid mat of wood to form a skidtrail. When the skidtrail is complete, dual-tired grapple skidders start at the farthest end of the road, picking up the mat of wood as they go. By traveling on the constructed skidtrail, shovel logging reduces rutting and soil disturbance.

Cable logging is another specialized method of extracting material on adverse sites, particularly on slopes greater than 35 percent. In cable logging, a long wire rope is suspended across the stand. A winch (the yarder) sits at the landing and pulls logs along the suspended cable. Depending on terrain and equipment, a cable system may simply drag logs from the stump, or it may completely lift them off the ground. Units can be relatively large, with extraction distances of one-quarter mile. With long extraction distance, it is critical to fully load the system on each turn. Thus, cable logging requires special skills among sawyers and choker setters. Product forms are limited by the possible load sizes for the cable. Planning is critical to meeting production and cost goals. However, LeDoux and others (1995) estimate that cable systems make 14 percent of the upland hardwood forest in the Southern United States economically operable.

Helicopters also can extract forest products where access is limited by soft soils or steep terrain. Helicopters are expensive to operate, so high hourly productivity is needed to achieve economic viability. Material to be removed is felled and bucked before the arrival of the helicopter and extraction crew. During extraction, teams of choker setters preset lines on the felled material in optimum load-sized bundles. The helicopter pauses in the woods just long enough for the choker setters to connect the drop line to a bundle. After a short flight to the landing zone, the helicopter releases the load and returns to the woods. Sirois and Stokes (1986) and Jackson and Morris (1986) observed a helicopter crew operating in cypress swamps in coastal South Carolina. The operation required a crew of 14, plus a front-end loader and a knuckleboom loader. At extraction distances of 900 to 2,900 feet, cycle times ranged from 1.74 to 5.35 minutes. Average production was about 3,100 cubic feet per scheduled hour of operation. Willingham (1989) described the initial configurations of helicopter logging with Scott Paper Company in the Mobile Delta. Their system consisted of manual felling followed by helicopter extraction to a riverbank, where logs were loaded on a barge. The system evolved to include tracked feller bunchers and a purpose-built helicopter to maximize efficiency.

Another application of helicopters is in steep terrain, where roadbuilding costs are high and ground-based extraction is difficult. Sloan and others (1994) reported on the use of a K-MAX logging helicopter for a shelterwood harvest in the mountains of Virginia. Working at an average extraction distance of 1,900 feet, the operation was estimated to produce 1,300 cubic feet per hour.

Helicopters are not limited by ground conditions; but they are limited by weather, altitude, and piece size. In order to accumulate full loads, helicopter logging requires a particular minimum volume per acre. Hourly costs are very high. The reported operating costs in 1986 were about $2,000 per hour, including support but not felling. To avoid delays, the landing zone must be large enough to safely handle the loading of 15 to 20 trucks per day. The primary advantages of helicopter logging are the reduction of soil disturbance associated with roads and skidtrails and the reduction in roadbuilding costs. With the fast cycle times, helicopters are also able to operate economically at longer extraction distances than most ground-based systems.

Operations training—A key component in forest operations technology is the skill and expertise of loggers. For decades, loggers have had opportunities for continuing education through workshops and seminars covering a range of topics. In the late 1980s, the Logger Education to Advance Professionalism (LEAP) program was initiated in the Northeastern United States to improve loggers' understanding of basic silviculture and resource management. Participation in continuing education was voluntary until the mid-1990s. When Occupational Safety and Health Administration (OSHA) released new logging safety regulations in 1996, it created a regulatory requirement for logging safety training. The OSHA rules closely followed the development of the Sustainable Forestry InitiativeK in 1995 by the American Forest & Paper Association. Member companies support education programs through financial contributions and by performance expectations established for their suppliers. In response, all but one Southern State developed some form of logger training and education (Forest Resource Association 2000). Oklahoma sends its people to courses in Arkansas. Curricula vary, but generally include safety and first aid, business management, best management practices (BMPs), environmental considerations, and forest management. Some courses are for supervisors, while others are for workers. Graduates receive formal recognition and may be required to remain current through continuing education. In 1999, 8,254 contractors and employees completed some form of a logger training and education course.

Operations prevalence and productivity—The 1990 Census (U.S. Census Bureau 2000b) reports 51,525 workers engaged in logging (Occupational Codes 494 and 496). Figure 15.1 shows the distribution of these logging workers across the South. Note that significant numbers of timber cutters are in counties with no forest

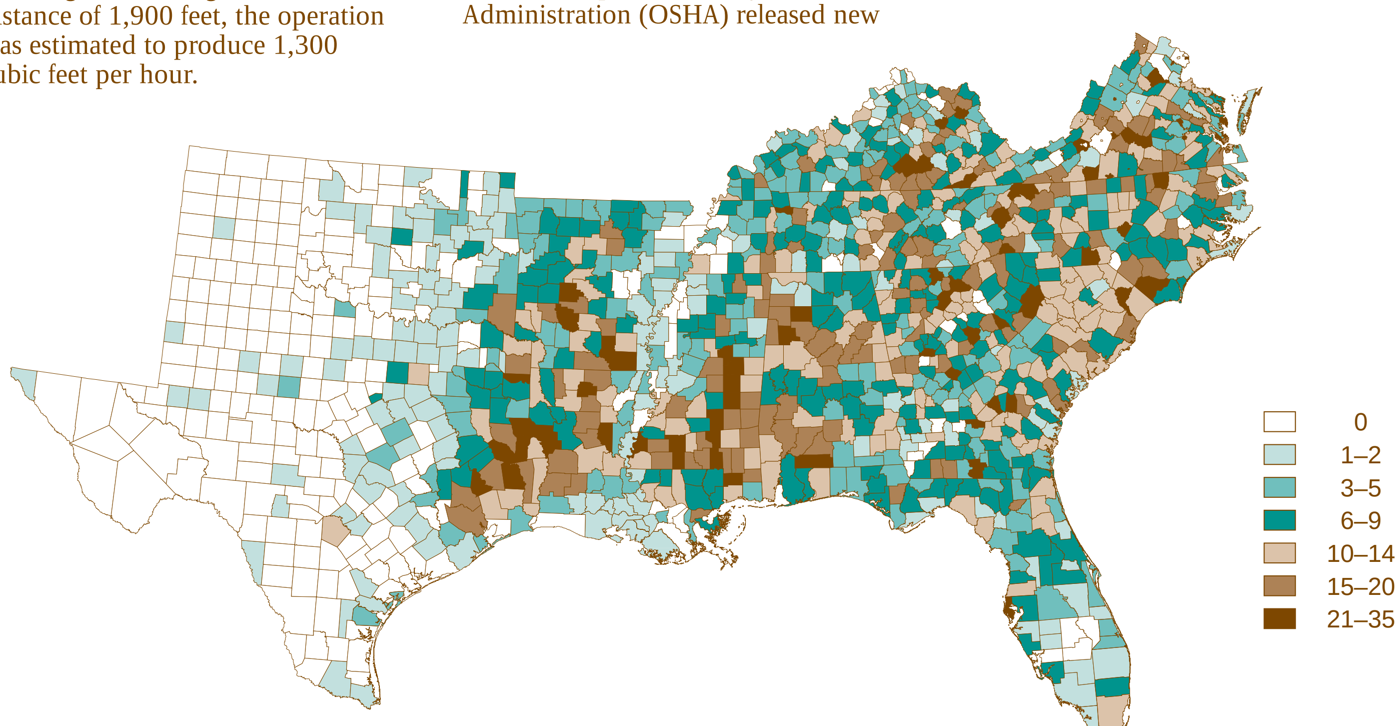

Figure 15.1—Distribution of logging workers in the South, 1990 (loggers per 100 square miles).

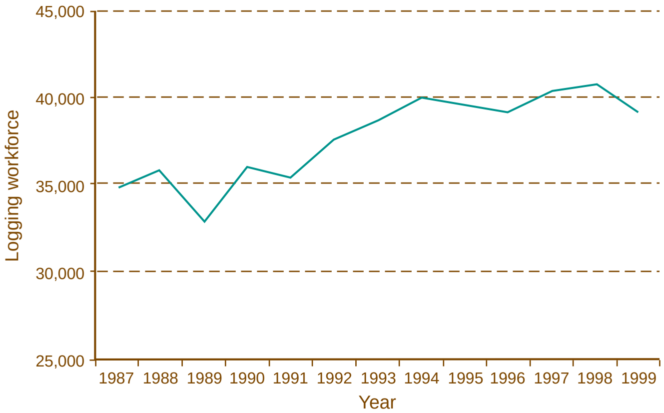

Figure 15.2—Changes in the logging workforce in the South, 1987 to 1999.

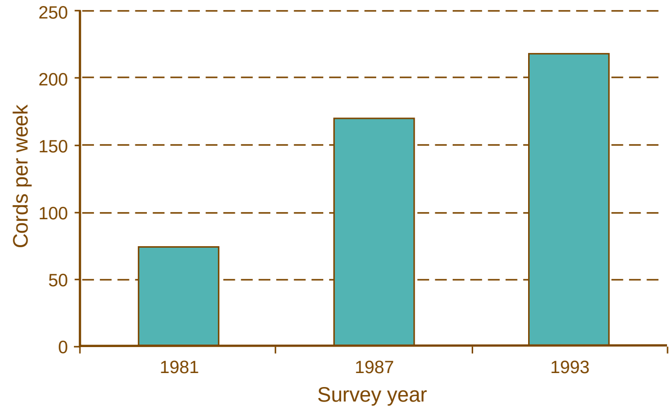

Figure 15.3—Average weekly crew production from pulpwood producer surveys, 1981 to 1993.

products output. This is particularly apparent in Texas, Oklahoma, and Florida, where there are concentrations of workers in metropolitan areas. These likely represent urban treecutters who clear land and perform arborist services. It is probable that other metropolitan areas have similar numbers of nonforest timber cutters. The ES-202 Covered Employment data suggest a 1999 southern logging workforce of 43,234, approximately a 15-percent increase over the last decade (fig. 15.2).

A number of studies document characteristics of these southern loggers. The Southern Technical Divisions of the American Pulpwood Association conducted a series of pulpwood producer surveys periodically from 1976 to 1993. The most recent report from the 1993 data (Munn and others 1998) located 8,700 contractors with 46,580 employees, operating in 11 Southern States (not including Kentucky or Oklahoma). Based on workforce estimates and pulpwood production reported, the survey sample was a nearly complete census of pulpwood producers. The most common harvesting configuration was a rubber-tired feller buncher working with grapple skidders to extract wood for tree-length transport. Most delimbing and topping were done with chainsaws, but delimbing gates were used in about half of the operations. Less than 3 percent of crews used in-woods chippers. From the receiving mills' perspective, about 78 percent of the wood volume was produced by only 28 percent of the crews. Almost half of the pulpwood logging crews sampled produced less than 70 tons per week. The periodic sampling of pulpwood producers shows a clear increase in crew productivity over the last 20 years (fig. 15.3).

In their analysis of successful logging contractors, Stuart and Grace (1999) reported that productivity increased by about 12 percent between 1994 and 1997. In the sample of the upper quartile of loggers, productivity averaged about 60,000 tons per year. Greene and others (2001) found that weekly production of Georgia loggers nearly doubled from 1987 to 1997. Capital investment per cord remained nearly constant over the decade, while labor productivity increased by 79 percent.

Combining the logging population data with TPO production figures provides an overview of logging productivity variations across the South (fig. 15.4). Productivity was negatively related to percent hardwood production. Productivity was highest on the Coastal Plains and decreased through the Piedmont to the Appalachians and Interior Highlands.

The various assessments of the logging workforce show a diverse range of forest operations in the southern forest. The majority of fiber is produced with high-production, ground-based systems. However, the majority of forest operators are small contractors with relatively low productivity. Technology has been developed to meet most conceivable forest conditions in the South. However economic viability limits the options of loggers and landowners.

Technology Impacts on Productivity and Management Choices

Rational selection of a management regime (rotation length, timing and type of intermediate treatments, etc.) should be based on landowner objectives, scientific management principles, and economic analysis. For any management prescription, there may be a range of alternative technologies that vary in objective attainment and cost. The manager must select a system that provides the greatest benefits at the least cost.

An economic analysis to determine the optimal rotation age will include the costs and timing of all management activities and the estimated returns. In the traditional (Faustmann) economic model, increasing harvesting costs extend the economically optimum rotation age. Prestemon and others (2000) analyzed data from the Southern Appalachians of North Carolina and Virginia to determine whether forest management decisions were consistent with economic viability. Results indicated that stand age increases with distance to markets, increasing slope, and decreasing site class. These findings would be expected under the traditional economic model and were observed across all ownership types (NIPF, industry, and government). Similarly, Brown (1990) analyzed harvesting activity on both wet and steep sites in the South. About 10 percent of southern forest sites were classified as adverse, mostly due to slopes over 40 percent. Harvesting rates on difficult sites were one-fifth of those on easily accessible sites. As a result, stands on difficult sites are older and have higher timber volumes. Barlow and others (1998) also found decreasing harvest rates with increasing slope and distance to roads; both factors increase harvesting costs.

While high harvesting costs increase rotation length, high site-preparation and establishment costs tend to reduce rotation length. The objective of intensive regeneration practices is to increase survival and growth, leading to economic maturity at an earlier age. The economic consequence is a shorter rotation to recover these costs earlier.

Haight (1993) added consideration of variation in future product prices to the traditional economic model. He based the timing of the final harvest on a comparison of current prices with a calculated reservation price. When prices exceed the reservation price, harvest is indicated. Plantinga (1998) notes that the reservation price model generally leads to longer rotations than the fixed rotation age calculation. Haight modeled a range of site preparation alternatives and found that the moderate treatment (chopping, burning, plant) had a higher expected present value than either an intensive or a natural regeneration option. In addition, this analysis found nearly a 20-percent increase in return due to timing the final harvest based on price expectations.

While an economic analysis may affect the selection of rotation length, in some cases the total costs may render any forest management uneconomical. May and LeDoux (1992) analyzed FIA plot data for Tennessee and estimated harvesting and stumpage prices for timberland. At medium stumpage prices, 51 percent of timberland was estimated to be profitable to harvest. At low stumpage prices, only 72 percent of the total timberland acreage could be economically managed. A similar approach was used in western Virginia (Worthington and others 1996). Under current market conditions, about one-third of the timberland in the study area would be unprofitable to manage.

Technology is being sought to reduce costs of forest operations. Such savings, however, cannot alter land management practices unless they are passed on to the landowner in the form of stumpage price increases. Most cost-saving technology now is being directed to controlling rising operational costs. Stuart and Grace (1999) noted that average logging costs per ton increased 16 percent between 1994 and 1997. During the same period, the Producer Price Index (PPI) for contract logging services only increased 4 percent (U.S. Department of Labor, Bureau of Labor Statistics 2000b). For the entire decade 1990 to 2000, the PPI for contract logging increased only 9 percent. Clearly, there is significant cost pressure on logging contractors. Costs of some site preparation treatments are also rising faster than inflation. Costs of prescribed fire nearly doubled in the last decade (Dubois and others 2001). Precommercial thinning and mechanical site preparation costs increased 30 percent. Costs for chemical treatments were up 20 percent, and those for hand planting rose 25 percent. Labor costs have increased with rising workers' compensation rates. With these price pressures, much of the technology to reduce costs is focused on maintaining profitability of logging contractors or for controlling wood costs at the receiving mill. Larger skidders and better delimbers are examples of developments to reduce costs through elimination of labor. It is unlikely that these cost savings will be passed back to landowners. The increase in mechanization as an approach to controlling logging costs has also resulted in more highly capitalized systems that derive efficiency from high volume production.

Impacts of Forest Operations

Forest operations alter the environment. Some of these effects are intended; others are undesirable consequences. Most impacts are associated with driving equipment and moving material in the forest. Soil, water, and residual vegetation can be affected. Effects must be considered in terms of their quantity, severity, persistence and location within the

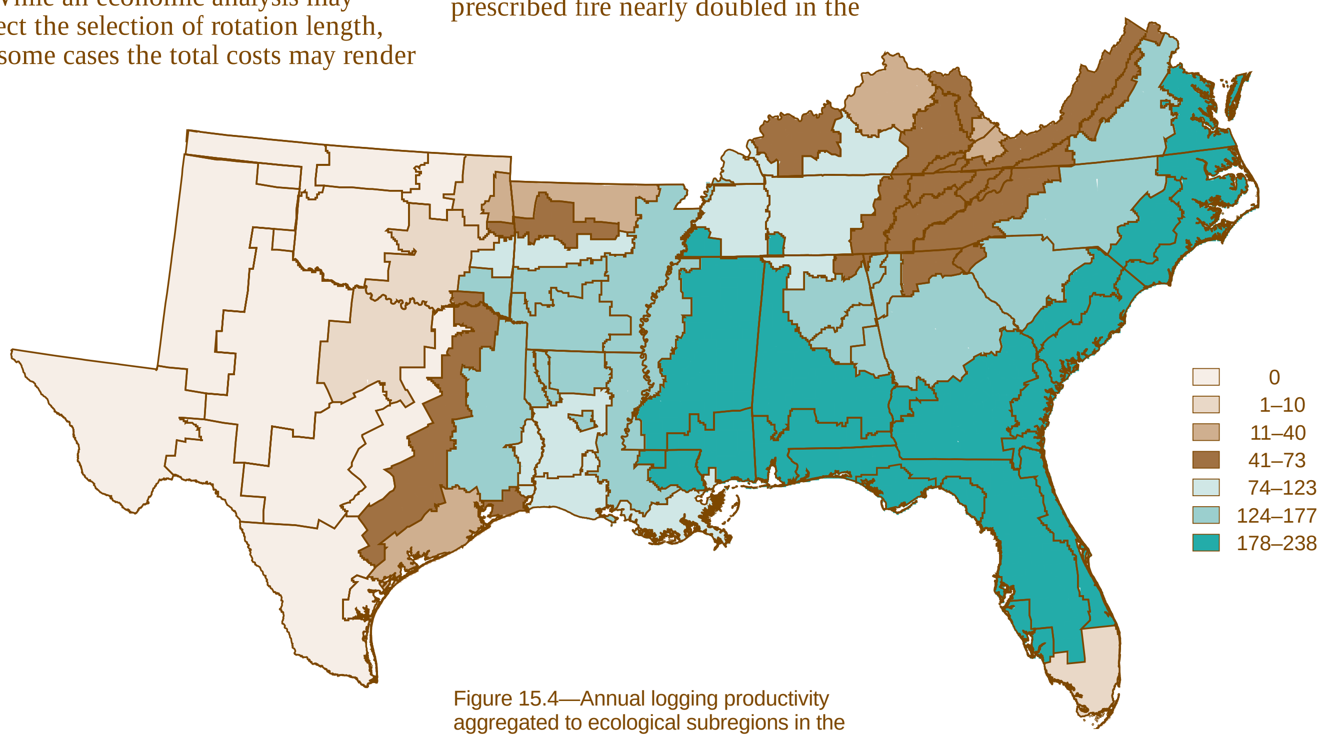

Figure 15.4—Annual logging productivity aggregated to ecological subregions in the South (thousand cubic feet per logger).

landscape. Some impacts are short-lived, while others may affect the long-term productivity of the forest. Impacts that are concentrated may be significant, while the same impacts spread across a stand may not be ecologically important. Chapters 21, 22, and 18 provide more information about the effects of forest management on water and soil.

The principal impact of most forest operations is soil disturbance. Soil disturbance results from road or trail construction, equipment traffic, and the dragging of material. Soil disturbance includes physical dislocation and loosening, compaction, or puddling. Disturbance effects are the cumulative result of all operations in a silvicultural system. Soil disturbance from felling is covered by soil disturbance from skidding, which is subsequently ameliorated by the soil disturbance associated with site preparation.

Conventional clearcut skidder harvesting systems cover about 15 percent of the stand in trails and landings. The most heavily impacted areas are the primary skid trails, gate delimbing areas, and landings. Detailed tracking of total soil disturbance on a Piedmont clearcut showed about 22 percent of the stand affected by more than five passes of machinery (McDonald and others 1998). At least 30 percent of the stand remains undisturbed, even in clearcuts. Reisinger and others (1988) summarized studies from the South and noted that 63 to 99 percent of the stand areas were undisturbed, depending on the system used.

More difficult sites tend to have a greater amount of undisturbed area than more easily accessible areas. Stuart and Carr (1991) and Stokes and others (1998) observed that disturbed area decreased with increasing slope. On slopes greater than 35 percent in central Virginia, skidtrail disturbance ranged from 3 to 10 percent of the stand. In contrast, Aust and others (1993) found 34 percent of a wet flat rutted.

Harvest intensity also affects the amount of soil disturbance. Kluender and others (1994) and Carter and others (1997) found that clearcuts and shelterwood cuts had similar amounts of skidtrail disturbance (about 15 percent of the stand). Shelterwoods, however, had more area in undisturbed condition. Single-tree selection had the least amount of soil disturbance, but that prescription calls for more frequent entries with additional impacts over time.

CTL systems carry wood rather than dragging it over the soil. The result is less soil disturbance. Vidrine and others (1999) and Lanford and Stokes (1995) found that seventh and fifth row thinning in pine plantations with a harvester/forwarder combination resulted in 11 to 30 percent of the total stand area disturbed by traffic. Both of these studies were on Coastal Plain sites in winter. Seixas and others (1995) compared five CTL configurations in various prescriptions and found the least disturbance occurred with a feller buncher, manual processing, forwarder system. About 26 percent of the stand area was disturbed. A system with a drive-to-tree harvester and forwarder disturbed 39 percent, and a horse logging crew disturbed 42 percent of the stands.

Cable logging reduces soil disturbance because wheeled traffic is eliminated in the stand. Disturbance still occurs from dragging logs, however, Miller and Sirois (1986) compared skidder and cable logging in southwestern Mississippi. About 16 percent of the cable units were disturbed, mostly in cable corridors. Skidders disturbed about twice as much area. Cable logging disturbance tended to be oriented up-and-down slope, while skidder disturbance was more irregular.

Forestry tires have gotten larger to provide better flotation and reduce rutting and disturbance. Wider tires typically reduce rut depth but increase track width (McDonald and others 1995). Thus, the primary application of wide tires appears to be on very soft soils where sinking and rutting are concerns. Carruth and Brown (1996), for example, noted that when moisture content exceeds 40 percent on lower Coastal Plain sites, the only systems that can operate are tracked feller bunchers and wide-tired skidders operating on trees and mats. On drier soils in eastern North Carolina, Seixas and McDonald (1997) observed that the least rutting developed with narrower tires on a forwarder rather than wider tires or tires with tracks. Rummer and Sirois (1984) observed that carrying larger loads on wider tires probably offset any reduction in soil loading.

Operational configurations that carry, rather than drag, materials generally produce less soil disturbance. Feller bunchers generate less disturbance than manual felling because trees are carried from the stump to the bunching location. Forwarders generate less disturbance during extraction than skidders because the load is off the ground. Swing machines have arms and rotating upper structures; they cause less disturbance than drive-to-tree designs. Swing machines can often reach into the stand to perform work without driving over every area.

Operating methods can also reduce soil disturbance. Designating skid trails can manage and minimize the amount of area impacted. Shovel logging is a method of logging that limits heavy traffic to a road of felled trees. When the trees are picked up, the underlying soil is minimally affected. Similarly, CTL operations can process trees in front of the machines, building a trail mat of limbs and tops. Seixas and others (1995) found that soil compaction was reduced under the heavier layers of the slash mat.

Cumulative soil disturbance can also be reduced by follow-up treatments to ameliorate adverse effects. BMPs typically call for vegetative stabilization of exposed soil that may be a sedimentation risk. Compacted areas may be subsoiled, ripped, or disked during site preparation to improve physical properties. On well-drained sites, survival and growth of loblolly pine have been positively affected by subsoiling treatments. On wet sites, bedding can create drier planting sites where harvesting has resulted in raised water tables (Aust and others 1998).

Accessibility to Various Ownership Groups

Forest operations accessibility depends primarily on economic viability. Economic viability, in turn, depends on whether the perceived value of the treatment exceeds the costs of implementation. A thinning, for example, may not have a short-run positive cash flow, but the increased value of the residual stand is expected to yield a profit over the rotation. Similarly, a landowner may realize no tangible return from creating a wildlife opening, but the intangible benefit of viewing wildlife may be deemed greater than the incurred costs. A prescription to achieve a given management objective establishes a set of operating conditions, such as extraction distance, volume per acre handled, seasonal restrictions, and slope, which will determine the operating costs for a particular forest operations technology. The prescription also determines the time frame over which expenses must be amortized and the values of the anticipated outcomes.

In the context of differences among various ownership groups, economic viability of forest management is primarily affected by the selection of management regimes and variations in tract size. Thompson and Johnson (1996) profiled NIPF landowners in Virginia and identified three subgroups: (1) farmer-owned, (2) other corporate, and (3) other private individual. Bliss and others (1997) surveyed NIPF owners in the Tennessee Valley and examined differences among income, ownership size, and management activity. Differences in accessibility of forest operations technology to any of these forest ownership groups depends on whether they fundamentally differ in their management objectives or in the size and composition of their forest holdings. See chapter 9 for additional information on the management objectives of various ownership groups.

Tract size may be the most important factor affecting economic viability of management activities. Row (1978) notes that the diseconomies of small tract size may reduce the willingness of landowners to invest in forest management. In the Virginia survey (Thompson and Johnson 1996), about 11 percent of the NIPF holdings were in tracts less than 10 acres; and 40 percent were in tracts less than 50 acres. The smallest average tract size was in the natural pine management type.

Generally, an economy of scale is realized by spreading fixed costs of ownership and management over more units of output (Cubbage 1983). In forest management, many costs must be recovered through value generation at some point in the management regime. For example, fire protection, boundary maintenance, and administration and planning are costs that vary little with tract size. In harvesting, costs for moving and planning accrue without respect to tract size. Greene and others (1997) analyzed the effect of tract size on harvesting costs. Their assumptions were based on a survey of recent timber sale volumes and tract sizes in Georgia. Figure 15.5 illustrates estimated production costs for three alternative systems using cost equations derived from the simulation analysis. Note that above 20 acres, all of the systems have relatively flat cost curves. Conversely, below 10 acres all of the systems demonstrate significantly increasing costs.

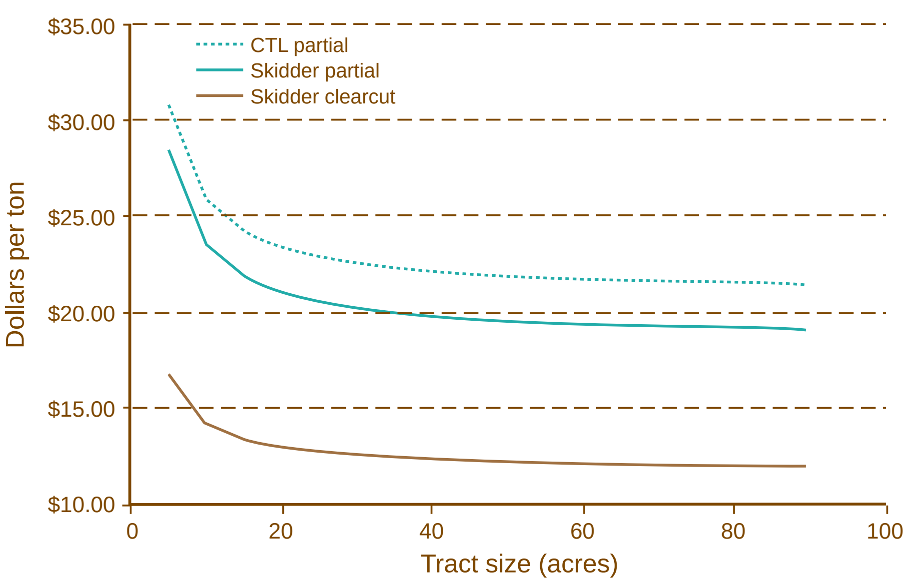

Figure 15.5—Predicted costs of harvesting 40 tons per acre in trees averaging 9 inches diameter at breast height.

Many studies have examined the effect of removal intensity on harvesting costs (Brummel 1993, Kluender and others 1998, Rummer 1998). Generally, there is little reduction in system productivity for prescriptions that leave a moderate residual stand, such as a seed-tree or shelterwood. However, when harvesting in small blocks, as with group selection or single-tree selection, productivity declines and costs increase. In selection harvests, other factors, such as the effect of selection criteria on average tree size, may be more important than tract size in determining economic operability.

Discussion and Conclusions

Forest operations technology is changing in the South. Tree-length logging and hauling have largely replaced shortwood operations. Labor-intensive bobtail crews, once the mainstay of pulpwood logging, are becoming harder to find.

The primary driver of change is economic viability. Labor costs have gone up, and the pool of able employees has been shrinking. The result has been a shift towards more mechanized operations with higher productivity per person. Site preparation and establishment costs have increased sharply. While new technology, such as fertilization, can increase yields, its costs must be closely examined to make sure the net financial return is positive. Rosenberg and others (1990) discuss the development and adoption of new technology in the forest products industry. They note that the adoption of new panel products in the 1970s and 1980s was not due to breakthrough technology (the basic technology had been developed 20 years previously), but rather to significant shifts in the price of veneer logs, which were the raw materials for conventional plywood. Relatively suddenly, the economic environment had changed.

A secondary driver of change has been the development of ecological issues. Water-quality concerns led to the development and promulgation of BMPs and logger training initiatives. Aesthetic values have become better defined and guidelines for minimizing visual impacts have been developed.

Our growing understanding of nutrient cycling and global carbon sequestration is leading to new technologies and opportunities in southern forests.

Neither economics nor ecology are optional. Southern forest management is not feasible if it cannot offer positive economic returns. Similarly, forest management is not tenable if it cannot maintain or enhance ecological functions. New technology must be constantly pursued to meet these continuing challenges. Yet Rosenberg and others (1990) observe that new technology is seldom the perfect solution to a problem. Innovations often have undesirable as well as desirable traits. The adoption process proceeds over time to reduce the adverse effects while optimizing the benefits. CTL is probably an example of this process. Modern CTL systems were developed and optimized in Scandinavia with very different labor, product, and cost structures. While CTL has some very good attributes, there are significant reservations about widespread adoption in the South at this time.

Another barrier to the adoption of new technology is the integration of forest operations. All parts of an operations system must be compatible with one another. Wood is hauled tree-length because the mills are set up to receive that form. Heavy traffic from ground-based systems defines the need for subsoiling. Changes in technology have to fit the existing framework of silviculture, products, processes, and culture.

Developments in information technology will be a central factor in all future management. Geographic Information Systems (GIS) permit the presentation, manipulation, and transfer and storage of map-type data. Increasingly, resource managers utilize GIS to develop and design prescriptions that better address the variation of conditions across the landscape. Geographic Positioning Systems (GPS) will allow operations technology to implement more complex treatment plans that are better adapted to site-specific ecological features.

Variation in the southern forest is a key factor that works both for and against innovation and new technology. Given the wide range of operating conditions from Virginia to Texas, it is unlikely that many new forest operations will find widespread application. New technology has to find its niche, and that niche must be large enough to warrant the necessary development costs. The variety of forest conditions, however, also supports innovation. Shovel logging, for example, was a niche system designed for upland sites in the Northwest. That concept, however, sparked new thinking about how to work in wet sites of the South.

Technology is developed in response to needs. Forest management defines a need, and technology delivers a solution. Forest industry defines a need for fiber in a specific form, and logging systems are modified to provide that form. The process of technological progress can be slow. Yet progress—both economic and ecologic—is evident in southern forest management. Even more new technology is waiting in the wings for the right need, the right place, and the right time.

Needs for Additional Research

Little specific information is available on the distribution and characteristics of niche technologies. Shovel logging systems, animal logging, CTL, and modern cable skidding are not well documented in the South. Land managers and contractors have little quantitative basis for the selection of appropriate technology on some tracts. This information will become more important as more site-specific prescriptions evolve. If timber markets expand, niche systems will also be sought for application on adverse sites, such as wet or steep terrain.

There is also a critical need for technology to manage smaller tracts, smaller diameters, and lower volumes per acre. Chapter 6 describes trends in ownership patterns, tract size, and fragmentation. It is an open question whether there are realistic silvicultural prescriptions for many small NIPF holdings, but the lack of mechanized operations that can operate economically where volumes are small affects many forest owners in the South.

The conventional ground-based operations that are used to produce the majority of timber in the South will continue to be refined by producers and equipment manufacturers through product development. However, research into the effects of planning and work organization may be able to generate cost savings and reduce adverse impacts.

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The southern forest resource assessment provides a comprehensive analysis of the history, status, and likely future of forests in the Southern United States. Twenty-three chapters address questions regarding social/economic systems, terrestrial ecosystems, water and aquatic ecosystems, forest health, and timber management; 2 additional chapters provide a background on history and fire. Each chapter surveys pertinent literature and data, assesses conditions, identifies research needs, and examines the implications for southern forests and the benefits that they provide.

Keywords: Conservation, forest sustainability, integrated assessment.