Forest Operations for Ecosystem Management

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Abstract

The evolution of mod& forest resource management is focusing on ecologically-sensitive forest operations. This shift in management strategies is producing a new set of functional requirements for forest operations. Systems to implement ecosystem management prescriptionsmay need to be economically viable over a wider range of piece sizes, for example. Increasing demands for more efficient fiber utilization and recovery from forest operations also put pressure on merchandizing the resource for maximum value recovery. Conventional forest operations are often not well-suited to meet these constraints. This paper reviews the development of functional requirements for forest operations in ecosystem management and summarizes regional investigations in the northeast, south, and Pacific Northwest.

Keywords: Costs, environmental impacts. forest operations. prescriptions

New Challenges for Forest Operations

Management is an active term. It implies applying knowledge and resources in an intentional method to achieve desired objectives. Resource managers are doers. What resource managers do, however, is being redefined by the evolution of the concept of ecosystem management. The ecosystem management approach specifies new objectives in resource management and places new constraints and values on the management process. Resource management is no longer about achieving single-commodity output targets, but rather about broader issues of restoring and maintaining healthy. productive ecosystems. Management performance is no longer measurable in cost/unit of production. but also considers the value of biodiversity. long-term site productivity, water quality, and esthetics.

True scientific management proceeds from principle to application (More 1997). As the underlying scientific principles of ecosystem management evolve, the questions shift from "what" to do b "how" to do it. Managers must have practical, cost-effective forest operations tools io manipulate the forest and achieve desired ecological conditions. However. the scientific principles of ecosystem management define the context. constraints, and value system within which management tools will operate and be judged. Developing management tools for ecosystem management is the new challenge for forest operations

While there is still discussion about the definition of ecosystem management, some key principles and constraints which affect forest operations have been identified. One of the most basic principles is that.

fundamentally, ecosystem management is about humans (Salwasser 1994). Human needs define resource consumption. With an expanding global population and a shrinking forest landbase, production of consumables such as paper, lumber, and fuel are placing an increasing demand on the forest resource. Human needs for non-commodity production of recreational, esthetic, and spiritual values are also part of the ecosystem management construct. Future human wants and needs are also considered by emphasizing sustainability- maintaining healthy and productive forest ecosystems for the use and enjoyment of future generations. As an integral component of the global ecosystem, humans demand both forest production and protection. While these two seemingly conflicting objectives are often at the core of debate, forests provide the opportunity to satisfy both if the underlying ecological processes of renewability and sustainability are understood.

A second key principle is that because of its broader, science-based approach, *ecosystem* management is inherently more complex than conventional single-output approaches. Considering the myriad ecological interactions requires an extensive knowledge base and detailed, site-specific prescriptions. Irland (1994) observed that the complexity and detail of ecosystem management will require an intensive application of resources to implement more sophisticated prescriptions. The complex prescriptions will be based on a mixture of quantifiable information, subjective assessments of intangible parameters, and informed judgements about incompletely understood ecological processes. Standardized "cookbook" prescriptions will be the exception and unique, flexible, adaptive strategies will be required.

As the principles of ecosystem management become clearer, new functional requirements are established for forest operations. For example. ecological requirements for natural regeneration in a particular forest type may specify certain light levels, soil conditions, and seed source spacing. These ecological requirements translate into functional requirements for the forest operation. The stand must be opened up to a certain density: stems selectively removed based on size. species. and spacing: the soil litter layer should be disturbed for seed catch. but not compacrcd. These functional requirements in turn define the management tool (forest operation) which can be employed to implement the management prescription

Some examples of the implications of ecosystem management which affect functional requirements for forest operarions include:

Older stands will be increasingly represented in the forest matrix. Older stands will contain a wider range of piece sizes which directly translate into equipment requirements for maximum cutting diameter and lift capacity. Older stands also contain a wider range of potential products. This should lead to a greater emphasis on sorting and merchandizing capabilities.

Stands will be manipulated regardless of product value. Prescriptions for forest health, stocking reduction, certain wildlife prescriptions, can generate a significant volume of low-grade timber. The cost-effectiveness of such operations will depend on forest operations which can merchandize and transpon the material to the highest value end use. Small-diameter timber is a special challenge to forest operations since many production costs are inversely related to piece size.

Protection of ecological values will be emphasized. Sustainability, uneven-aged management and ionger rotations will put a premium on forest operations which minimize residual site impacts. Soil compaction and residual tree damage are long-term impacts which may reduce growth and promote mortality. In some cases, disturbance and damage to non-woody vegetation may be critical. These constraints require light-on-the-land technologies for forest access and extraction.

Prescriptions will attempt to fit within the range of natural disturbance. The scale of natural disturbances varies from single-tree mortality to watershed-scale disruption. Most disturbances, however, are at the smaller end of the scale. Mimicking natural disturbance will require operations that can move in for small, scattered areas. Therefore, move-in requirements for transport and access development will need to be minimal.

Large units of mature forest will be unroaded or minimally roaded. Timber extraction costs are primarily a function of transpon distance and infrastructure capital costs. Reducing road networks will extend extraction distances beyond current practices. Generally this will require systems with larger payloads

These few examples show how management requirements will affect the development and selection of forest operations. The challenge is to integrate ecological principles with engineering practice

Table I-Cut and residual stand attributes for three silvicultural prescriptions

Stand attribute	Conventional shelterwood		Irregular shelterwood		Thinning	
	cut	Residual	cut	Residual	cut	Residual
Trees/ha	124.3	63.3	143.3	46.2	67.2	113.7
Basal area (m^3/ha)	18.5	8.4	21.3	4.2	10.8	16.5
Mean d.b.h. (cm)	43.4	41.1	43.4	34.0	45.2	42.9
Total volume (m^3)	144.1	70.0	160.2	28.0	91.7	133.7

Recent Forest Operations Studies

In order to better understand the functional issues of applying ecosystem management prescriptions, a series of studies has been conducted in three forest regions of the United States. These studies are examining forest operations from both a technical perspective and an ecological perspective. What are the costs and performance capabilities of alternative systems used to implement ecosystem management prescriptions? Equally as important, what is the ecological performance of these systems, both in terms of anainment of ecological objectives and avoidance of adverse ecological impact? These studies have been coordinated and supported through the Wood Utilization in Ecosystem Management project at the USDA Forest Service Forest Products Laboratory.

Cable Logging in the Appalachians

Cable yarding has been used in the Appalachian hardwood region for timber extraction on steep slopes. Typically, cable systems are used in relatively large clearcut units. There is growing concern, however, about the visual and ecological effects of clearcutting. Thus, resource managers are searching for information about the effect of using conventional cable logging equipment in alternative prescriptions.

A case study was conducted on the Nantahala National Forest near Franklin, North Carolina to monitor production rates and costs, and to measure residual stand damage and soil disturbance, of cable logging in partial cut prescriptions. Three cutting units were harvested with the following silvicultural prescriptions: conventional shelterwood cut, irregular shelterwood cut to initiate a two-aged structure, and crown thinning (Table 1). All of the units were located in a yellow-poplar, white oak. and red oak forest type on good to excellent sites The units averaged 2.8 ha on slopes of 30 to 50 percent

The silvicultural prescriptions were marked and all of the designated cut trees were felled before yarding commenced. Four to five skyline corridors were located after felling. Each unit was harvested using a two-drum yarder with an 11 -meter tower. The system was rigged as a live skyline with a gravity carriage that locked to a stop on the skyline. Maximum uphill yarding distance ranged from 165 to 300 m. Average lateral yarding distances ranged from 8 to 14 meters with maximum lateral distances from 40 to 45 m.

Working from the detailed elemental production data, a cycle-time equation was developed and used with the THIN model (LeDoux and Butler 1981) to simulate cable yarding operations and estimate standardized production and costs. Computer simulation was used in a sensitivity analysis of harvesting costs and revenues for 13 variations of silvicultural treatments, including group selection and diameter limit cuts in addition to the three treatments actually studied in the field (Baumgras and LeDoux 1995). The simulations tested the effects of varying harvest intensity and cut tree size.

Results of the economic analysis demonstrate the sensitivity of cost and revenue to silvicultural treatments: logging costs ranged from $5.64 to $14.90/m^3, gross revenues from $20.84 to $46.26/m^3, and net revenues from $143 to $6938/ha. Due to the composition of the initial stands, the group-selection diameter-limit, and heavy shelterwood cuts all yielded large cash flows. However, treatments which required significant reductions in harvested volume per hectare and/or volume per cut tree resulted in large reductions in estimated net revenue--as much as $4967/ha for the conventional shelterwood cuts and $3727/ha for thinnings. There also were significant variations in net revenue resulting from location and dimensions of the group selection units. These estimates reflect the relatively low Cost of a shop-built yarder, which is commonly used in southern Appalachia

While cost is one significant consideration, the ecological performance of cable logging in partial cuts is also important. Soil disturbance was sampled immediately after yarding using randomly located transects. In addition, 0.0809-ha fixed-radius plots were installed to sample residual stand damage. Tree damage was classified by type and dimension. There was no significant difference among the three silvicultural treatments in terms of areal soil disturbance. More than 70 percent of the total stand area was undisturbed and only 10 percent of the area was deeply disturbed or compacted. Most of the deeply disturbed area was associated with portions of the corridors where skyline deflection was limited. The residual stand damage surveys indicate that logging damage was significantly greater on the two sheltenvood units than on the thinning unit. Sixteen percent of the residual trees were destroyed on the conventional and irregular shelterwood units compared to only 5 percent on the thinning unit. Trees destroyed were uprooted or broken off, generally during felling operations. Bark wounds occurred on 13 percent of the shelterwood trees while only I percent of the residual stand in the thinning unit received this type of damage.

Cable logging can serve as a valuable management tool in a range of management prescriptions for upland hardwoods. This study quantified the impact of the specifications placed on forest operations by sitvicultural prescriptions. Changing from a shelterwood cut removing 70 percent of basal area, for example. to one removing 50 percent of basal area reduced net revenues by about 40 percent. Selection criteria for residual trees which affect average cut tree volume also impact the costs of the operation. Stand damage measures highlighted the importance of proper planning and training to implement alternative harvest schemes. Soil disturbance was significantly affected by corridor placement and rigging which indicates that improved planning and control of harvesting operations can moderate environmental impacts. Residual stand damage was affected by corridor location and felling skill.

Alternative Operations in the Western U.S.

A significant percentage of the forested area in the western U.S. consists of stands that have been altered over time by human activities, especially fire suppression. and are now being damaged by drought, insect attack, and wildfire. In general, the ecological prescription to restore stand health focuses on reducing the number of trees per acre. Direct reduction of fuel loading can minimize the risk of a catastrophic wildfire and enable the re-introduction of natural fire cycles.

With a wide range of stand, terrain, and marketing options across the West, a range of alternative forest operations is needed which can perform selective removals in low-grade material. A series of operational trials was conducted to examine the costs and performance of forest operations for forest health prescriptions.

In California, *a* forest health prescription was developed for a mixed conifer stand that had been partially logged by railroad in the 1940's and had naturally regenerated. The stand had a wide distribution of diameter classes and a range of species, but was overstocked. Many of the larger trees had been killed during the drought of the previous years. A thinning prescription was developed with two primary objectives: enhance habitat for spotted owls, and reduce fuel loading. All live trees over 46 cm DBH and all snags over 41 cm DBH were retained. The understory was thinned, and pockets of small trees were left as wildlife screens. Three different forest operation systems were compared in this treatment (Hartsough et al. 1994).

A second operational trial was conducted on the Mescalero Reservation in New Mexico (Watson et al. 1995). Several stands were treated to reduce basal area through selection of dying and at-risk trees. A feller/buncher-skidder-chipper system was used to fell and extract material for chipping as pulpwood.

The third operational trail was conducted in northeast Washington, on the Colville National Forest (Barbour et al. 1995) These stands were characteristic of the 50-60-year-old fire-generated stands common in the intermountain region. Stocking averaged over 2470 stems per acre, and more than half the trees were smaller than the minimum utilization specification at local mills. These stands were thinned to increase growth, reduce mortality, decrease fuel loading, create winter browse sites. and to move the stands toward a later-older successional stage. A harvester-forwarder system was used to perform the operation.

Conventional time and motion studies were conducted in each trial to determine production and costs. Subjective observation of soil disturbance and measures of residual stand damage were also recorded Table 2 compares the five different forest operations systems on an array of performance characteristics

Some general trends are apparent from these studies Harvester-forwarder systems are more expensive per unit volume handled. They become economically

Table 2—**Characteristics** of alternative forest operations **used in forest health prescriptions**

Characteristic	Forest operation system				
	F/B[a]-skidder-flail-chipper	F/B-skidder-processor-load-chip	F/B-harvester-skidder-load-chip	Harvester-forwarder-load-chip	Harvester-forwarder
Capital Cost ($)	1.2-1.5M	1.8M	2.0M	1.3M	600-900K
Hourly Cost ($/SH)	530-650	540	590	380	120-180
Stump to Truck ($/green ton)	10-18	15	18	26	3-7 (harvest only)
Product mix	Clean chips, sawlogs	Fuel chips, sawlogs	Fuel chips, sawlogs	Fuel chips, sawlogs	Sawlogs
Soil disturbance	medium to high	medium to high	medium to high	low	low
Slope limits	50%	50%	50%	30%	30%

[a]F/B is feller-buncher.

feasible by recovering higher value per unit volume. Single-entry chipping systems require a high volume of chippable material to justify move-in costs and to keep the expensive chipping equipment fully utilized. Cold decking material for subsequent chipping (a two-entry system) can operate with a wider range of product mixes since the chipper can be fully utilized when it is on sire. Whole-tree systems realize higher recovery rates and may be appropriate where markets exist for fuel chips and the silvicultural prescription permits high biomass removal.

Harvesting costs for all systems decrease as tree size increases. Since diameters are generally small in the overstocked stands typical of forest health cuttings, smaller, cheaper machinery can be utilized. However, it is important to be able to handle the occasional large diameter trees. Harvesters and forwarders tend to be more sensitive to tree size effects than feller-bunchers and skidders.

Forwarding products from the woods, in general, results in lower residual stand impacts. Soil disturbance is reduced and damage to residual stems is minimized when logs are carried rather than dragged. Systems which incorporate harvesters may further reduce soil disturbance by providing a mat of limbs and tops on the trails. Leaving residues in the woods avoids disposal problems at landings, enhances nutrient cycling, and provides better visual quality. However, in stands where existing fuel loading is high it may be inappropriate to leave residues in the woods.

Secondary transport requirements must also be considered in selecting a forest operation. Chipping systems are restricted to areas with higher standard roads that can carry highway chip vans. The high woodflow associated with most chipping systems is often achieved by keeping extraction distance down. This translates into a higher road density. Forwarding systems. on the other hand, are less sensitive to extraction distance costs and may be preferred when road density is relatively low.

The selection of a harvest system for a given management prescription depends on many factors and a large number of alternatives are available. It is important to remember site-specific factors such as transport distance or local market conditions in addition to operating system characteristics in making a system selection. Unique combinations of existing equipment and modifications to methods can provide management with flexibility in addressing prescription requirements

Alternative Operations in the South

The traditional objective of resource management has been commodity production. This is especially true in the southern United States where private forest

Table 3—Soil disturbance caused by alternative forest operations

System	Disturbance Classification (% total area)			
	Undisturbed	Slightly disturbed	Mineral soil exposed	Deeply disturbed
Manual-forwarder	44	53	3	0
Manual-horse-forwarder	50	45	5	0
Feller/buncher-manual-forwarder	56	41	4	1
Drive-to-tree hatvester-forwarder	29	58	11	1
Swing-to-tree harvester-forwarder	40	56	3	0

landholdings represent nearly 75 percent of the forest landbase. Conventional forest operations in the South have been developed to minimize production cost. However, even in private ownerships, there is growing concern about the sustainability, public perception, ecological effects of current management practice. Drive-to-tree feller-bunchers and grapple skidders can be used effectively with acceptable environmental impacts in clearcut operations. In selective cutting systems, however, the effectiveness of a drive-to-tree tree-length system is reduced. More extensive use of uneven-aged management, natural regeneration, and selection cutting will require alternatives to the conventional operations.

Cut-to-length (CTL) technology was examined as an alternative to skidder systems in a study on the Tuskegee National Forest in Alabama. Five variations of CTL operations were tested in four types of selective cutting prescriptions. The forest operations included: manual felling with forwarder extraction; manual felling with horse prebunching and forwarder extraction; feller-buncher with manual processing and forwarder extraction; a 3-wheeled harvester with forwarder; and a 4-wheeled swing-to-tree harvester with forwarder.

The prescriptions varied in removal intensity, removal openings size, and tree size. Conventional time and motion studies were conducted to determine production and costs. Soil disturbance was assessed on transects through the stands. Damage to residual trees was documented on sample plots.

Seixas et al. (1995) summarized the comparison of soil disturbance. There was no significant difference in soil disturbance level due to the different types of silvicultural prescriptions. However, there was a significant difference in soil disturbance due to the type of system employed (Table 3). The feller-buncher/forwarder system had the least amount of disturbance and the j-wheeled harvester system produced the most disturbance.

In general, the soil disturbance was a result of either machine movement (soil-tire interaction) or piece movement (positioning felled trees or parts of trees). Variations in soil disturbance could be explained by the different methods each system used in felling, processing, and transporting. While system differences were apparent, overall the CTL systems produced significant disturbance in less than IO percent of the stand.

Productivity data from the study is being incorporated into a harvesting simulation study (Wang and Greene 1996). The harvesting simulation is based on stand maps generated by computer. Images of harvesting machines are maneuvered through the stand by the simulation operator. Combining distance and tree information with the production equations from field studies provides an estimate of production and cost. The primary advantage of the harvesting simulation approach is that it permits modeling different systems operating in identical stands. It also permits the same stand to be treated with a range of prescriptions. Currently, the simulation has been used to investigate the relative impact of removal intensity on feller-buncher productivity.

Concluding Remarks

Management is fundamentally about translating prescription into practice. In this translation, the manager seeks tools that achieve the required ecological manipulations, minimize undesirable side effects, and are economically acceptable. Ecosystem management is altering this entire decision process. Ecological goals are becoming more complex, there is new sensitivity to the ecological impacts of forest operations, and the costs must be minimized while placing values on many non-traditional outputs.

Successfully implementing ecosystem management will require the development of new management tools (forest operations) and the adaptation of conventional practices. Just as the debate over the scientific principles of ecosystem management has been developed and refined over a period of years, forest operations will have to be developed and refined.

Forest operations research is beginning to develop the knowledge needed to make appropriate selection of forest operations. What systems can be utilized to achieve certain silvicultural goals? How do mechanical factors such as equipment specifications affect ecological parameten? What requirements of ecosystem management are not fully met by existing methods of working in the forest? These questions are being prompted by the evolution of the ecosystem approach to forest management. Successful implementation of ecosystem management requires an ongoing research effort tdprovide reasonable answers.

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