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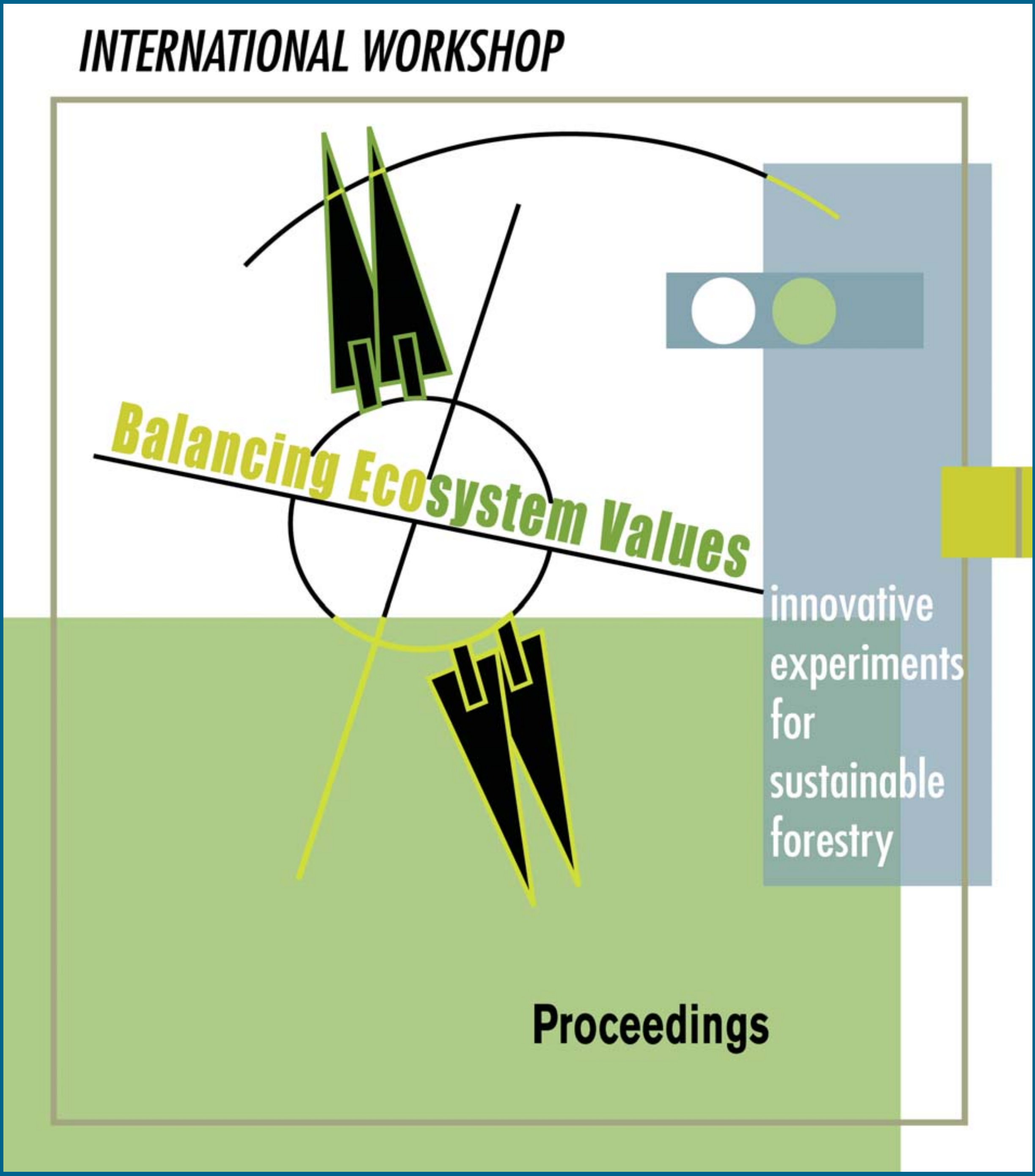
Balancing Ecosystem Values: Innovative Experiments for Sustainable Forestry

Charles E. Peterson and Douglas A. Maguire, Editors



EDITORS

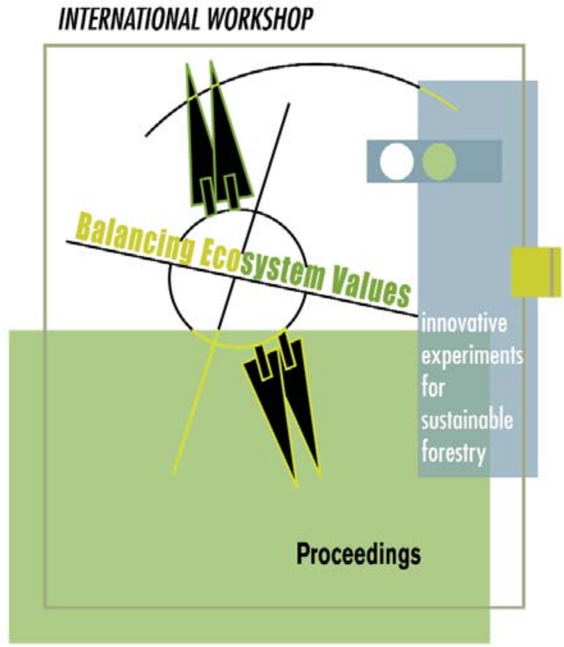
Charles E. Peterson is program manager, Resource Management and Productivity Program, Pacific Northwest Research Station, Portland Forestry Sciences Laboratory, 620 SW Main St., Suite 400, Portland, OR 97205; Douglas A. Maguire is an associate professor, Department of Forest Science, Oregon State University, Corvallis, OR 97331.

Technical editor: Rhonda Mazza, Pacific Northwest Research Station, Portland Forestry Sciences Laboratory, 620 SW Main St., Suite 400, Portland, OR 97205

Scientific reviewer: Toni De Santo, Pacific Northwest Research Station, Juneau Forestry Sciences Laboratory, 2770 Sherwood Ln., Juneau, AK 99801

Graphic designer: Jenny Beranek, Beaverton, OR 97006

Cover graphic by Sandra Arbogast, College of Forestry, Oregon State University Corvallis, OR 97331



Balancing Ecosystem Values: Innovative Experiments for Sustainable Forestry

Charles E. Peterson
and Douglas A. Maguire, Editors

August 15-20, 2004
Portland, Oregon

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ABSTRACT

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Balancing Ecosystem Values: Innovative Experiments for Sustainable Forestry is a compendium of more than 40 contributions from Asia, Europe, and North America. The theme encompasses experiments implemented at an operational scale to test ecological, social, or economic responses to silvicultural treatments designed to balance the complex set of objectives currently targeted in sustainable forest management. Several invited and plenary papers emphasize the variety of outcomes demanded by the public, as well as the essential role that these long-term studies will play in allowing natural resource managers to make better-informed, science-based decisions. A broad spectrum of silvicultural treatments and systems are covered, as are simulation runs with different types of models and discussion about design challenges for scaling up from stands to landscapes. Diverse forest ecosystems, stand structures and plant, animal, and fungal species are also considered. The conference included 2 days in the field where participants saw several types of the comprehensive field experiments firsthand. The conference concluded with a critique from state, private, and public land managers.

KEYWORDS: Sustainable forestry, biodiversity, variable retention, public acceptance, adaptive management, silvicultural options, landscape-level effects.

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FOREWORD

Various forest management objectives have changed dramatically in recent years for lands under federal and state ownership, and many of the traditional objectives have expanded in scope and complexity. Past silvicultural studies tested the ability of specific treatments and systems to regenerate forests of desired composition and structure to meet society's needs, with primary emphasis on wood production. Wood production remains a primary economic objective for many private and nonindustrial landowners, but on federally managed forests and rangelands, changing societal values now demand ever more comprehensive approaches to forest management that integrate social, ecological, and economic goals. As a result, many recent (past decade) silvicultural experiments have become multidisciplinary in scope and include restorative objectives, novel and untested silvicultural treatments, or traditional approaches expanded to operational scales.

Current silvicultural or manipulative forest ecological experiments need to address a variety of responses to changes in forest structure and composition imposed by treatments. Meeting diverse public interests necessitates experiments designed by interdisciplinary teams (e.g., forest ecologists, sociologists, biologists, economists, and silviculturists) where ecological, social and economic objectives are attained as joint outcomes, in addition to wood production.

Individually and collectively these studies represent major investments by research and federal and state land management organizations to find practical solutions that meet public demands. In addition to clean air and water, people want healthy and appealing forest environments for recreation and leisure, wildlife habitat, biological diversity characteristic of late-successional stands, and an output of wood or other forest product that supports local economies. Solutions based on silvicultural experiments implemented at an operational scale, and that track a variety of responses, enhance the public's confidence in the ability of land managers to successfully achieve the desired mix of objectives.

These proceedings present numerous examples of operational-scale experiments from North America, Europe, and Asia; many of these experiments are in the early stages of implementation and thus unknown to many in the professions of forestry and applied ecology. In addition to presented research and poster sessions indoors, this conference included 2 extraordinary days in the field. On the first day, participants toured the Washington State Capitol Forest to view options for young-growth management. On the second day, participants had the option to visit several sites of a density management study on land managed by the Bureau of Land Management in western Oregon, or tour replications of the Demonstration of Ecosystem Management Options study on the Gifford Pinchot National Forest. Quality presentations held on site fostered rich discussions among participants. Unfortunately, space did not allow for inclusion of field abstracts and handouts in these proceedings.

This conference represents the second phase of a more comprehensive effort by U.S. Forest Service Research and the International Union of Forest Research Organizations (IUFRO) to highlight these newer, long-term, operational experiments. It follows a smaller IUFRO workshop, *Applied Forest Ecological Experiments*, held August 5-7, 2003 in Davos, Switzerland. The culmination of this effort will be a special session of the 2005 IUFRO Congress in Brisbane, Australia, entitled "*Long-Term, Multi-Purpose Experiments in the Forest Sector*."

Charles E. Peterson and Douglas A. Maguire,
Editors

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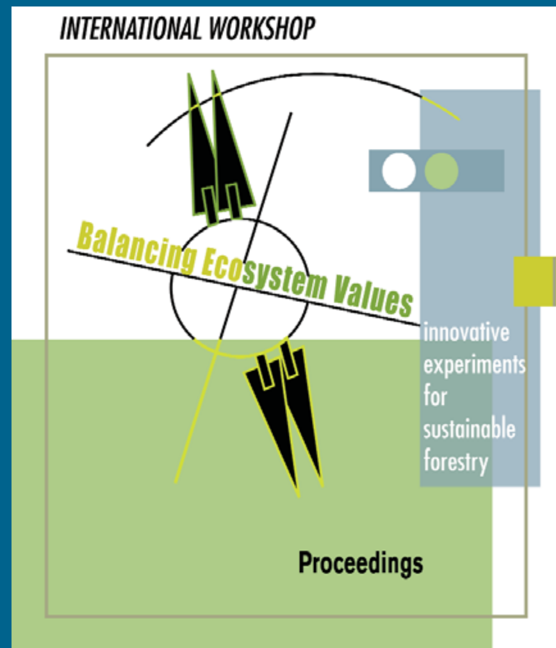
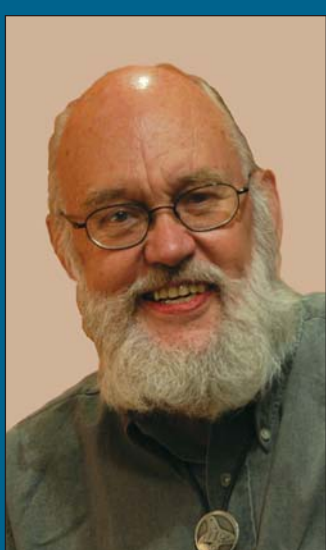
There are several key people we need to acknowledge in this effort. We greatly appreciate the work of Nathalie Gitt and Joe Holmberg at Oregon State University for the initial webpage design, the logo and cover design, compiling the pre-conference handouts, and helping with the technical needs of all the presentations. John Cissel (Bureau of Land Management), Jon Nakae (Gifford Pinchot National Forest), and David Marshall (PNW Research Station) all did a tremendous job organizing the field tours, including the safety precautions.

Jon Nakae (Gifford Pinchot National Forest), Dan Luoma (Oregon State University), and Charley Peterson (Pacific Northwest Research Station) present findings from DEMO on mycological diversity and green-tree retention harvests. *Photo by Cara Nelson*



KEYNOTE PAPERS


Fred Bunnell


Jerry Franklin


Klaus von Gadow


John Innes

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Adaptive Management for Biodiversity in Managed Forests – It Can Be Done

Fred L. Bunnell[1]

ABSTRACT

Sustaining biological diversity and sustaining fiber production are competing objectives. Objectives for biological diversity are ill-defined and appropriate practices are little understood, but practitioners are compelled to act. The latter two features make the task suitable for adaptive management, provided it is not too complex, too costly, or too lengthy. This case study, over 1.1 million ha in coastal temperate rainforest of British Columbia, shows that it can be done. This paper describes what was done for each of the four main steps in an adaptive management program. Step 1, creating clear objectives, exploited the criteria and indicator approach yielding an operational definition of biodiversity and three broad indicators (ecosystem representation, habitat, organisms). Step 2, planning and practices to attain objectives, introduced stewardship zoning into strategic planning and applied retention systems over the entire tenure. Step 3, creating a monitoring system to assess proximity to objectives, is the most intellectually challenging due to the complexity of biodiversity, but can be summarized within a cross-design. The final step, feedback to management, is where we most often fail. Ways of reducing the likelihood of failure and examples of feedback to management practices are described. These latter activities close the adaptive management loop.

KEYWORDS: Adaptive management, biodiversity, forest management.

INTRODUCTION

There are few more encompassing words than "biodiversity." Few undertakings are more complex than forestry. The complexity of sustaining biodiversity in managed forests fits it well to the promise of adaptive management. Adaptive management is a formal process for continually improving management practices by learning from the outcomes of operational and experimental approaches. There are, however, few success stories for adaptive management in forestry. It is too early to pronounce this case study a success or a failure. Over its course, there have been corrective nudges to modify practices. I first review the problem and the ecological and social setting, then describe the four major steps of adaptive management and how they were enacted in coastal British Columbia (BC).

THE PROBLEM

Forestry has addressed multiple values for centuries. Incorporating biological diversity as a product of forests was a departure from other values in several ways. Foremost was the lack of an operational definition for biodiversity. Within 6 years of the Convention on Biological Diversity, more than 100 competing definitions had been published. Moreover, existing agreement promised only confusion – all species were considered part of biological diversity, but we did not know what all those species were or how they would respond to forest practices. We did know that whatever we did to a forest, including nothing, favored some species and disadvantaged others. Theory and experience were disconnected from practice as never before (Bunnell and Chan-McLeod 1998).

[1] Honorary Professor, Centre for Applied Conservation Research, Department of Forest Sciences, 2424 Main Mall, Vancouver, BC V67-1Z4, Canada. Email: fred.bunnell@ubc.ca

Foresters accepted responsibility for sustaining two competing values – wood products and biodiversity. Properly managed wood products are renewable and their production can be sustained indefinitely. Moreover, they have a much smaller "ecological footprint" than substitute products (Lawson 1996). Managing to create renewable products with a small ecological footprint was a good thing. Even if we could not define biodiversity well enough to be confident that it was a good thing to sustain, we often were charged to do so. Efforts to sustain a few elements of biodiversity (e.g., spotted owl (*Strix occidentalis caurina*); and marbled murrelet (*Brachyrhamphus marmoratus* Gmelin)) revealed that trying to sustain all elements would create competition between two desired products.

Exacerbating the issue is the fact that sustaining biodiversity in forested systems confronts special difficulties; for example, more species reside within forests than in other plant communities, we modify forests to extract products, and forestry must be planned over large areas and long periods. See Bunnell and Chan-McLeod (1998) and Bunnell et al. (1999) for a fuller treatment.

A succinct statement of the problem is, "How can we sustain biological diversity in managed forests?" The problem will not go away, nor will most difficulties diminish. The largest features of the problem – little clarity about appropriate practice, need to act despite clarity – appear well suited for adaptive management, though complexity is an obvious challenge. Opportunity arose to cast the problem in an adaptive management framework in coastal British Columbia. Before describing how adaptive management was applied, I describe the coastal setting.

THE SETTING

Physical Landscape

The area under forest management extends over 1.1 million ha of separate pieces along the coast of British Columbia—Vancouver Island, Gulf Islands, Queen Charlotte Islands and mainland coast. Watercourses of various sizes and gradient are abundant. Much of the terrain is rugged and mountainous. Valleys usually are deep, glaciated troughs, with gentle slopes restricted to valley floors. Ridge tops defining valleys commonly rise over 1000 m with peaks considerably higher. Gently sloping uplands are uncommon, and valley sides often are steeper than 30° or 60 percent. On gentle slopes and in the coastal lowlands, glacial and post-glacial deposits generally bury bedrock. On steeper slopes, weathered till is susceptible to debris slides and debris flows. Most relief is perpendicular to prevailing weather systems, so annual precipitation differs greatly from windward to leeward sides. Windward areas are among the wettest temperate regions of the world. Measurable precipitation usually occurs 200 or more days of the year, and annual totals in most of the region range from about 175 to 440 cm. Throughout the year, the ocean modifies temperatures, so that winters are relatively mild and summers are relatively cool (except in the driest portions).

Ecological Setting

The climate of the region encourages a landscape dominated by coniferous trees. Strong topographic influences on climate yield three distinct forest types (biogeoclimatic zones of Meidinger and Pojar 1991). The coastal Douglas-fir (CDF) zone occurs on the southern, rainshadow portion of the tenure. It represents about 1 percent of the tenure, and is present primarily on private land. The most common tree species is Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Western redcedar (*Thuja plicata* Donn ex D. Don), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), arbutus (*Arbutus menziesii* Pursh) and red alder (*Alnus rubra* Bongard) are frequently present. This zone receives about 65 to 125 cm of precipitation annually, about 5 percent as snow. The coastal western hemlock (CWH) zone occurs throughout the tenure outside of the rainshadow, representing about 87 percent of the tenure. The most common tree species usually is western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), though western redcedar is common. Douglas-fir is naturally restricted to drier southern and southwestern slopes. The zone receives more rain than any other zone in the province, typically 100 to 440 cm of precipitation (more in some areas), with snowfall contributing about 15 percent in the south and 40 to 50 percent in the north. The CWH is broadly equivalent to coastal temperate rainforest and hosts some of the largest, longest-lived trees in North America. The mountain hemlock (MH) zone represents about 12 percent of the tenure and occurs above the CWH, about 900 to 1800 m in the south and 400 to 1000 m in the north. Alpine tundra may exist above it. The most common tree species are mountain hemlock (*Tsuga mertensiana* (Bongard) Carriere), amabilis fir (*Abies amabilis* (Dougl. ex Loud.) Dougl. ex J.Forbes) and yellow-cedar (*Chamaecyparis nootkatensis* (D.Don) Spach). The zone receives more total precipitation than the CWH (about 170 to 500 cm annually), but 20 to 70 percent falls as snow. These are not productive forest sites, and tree growth becomes progressively poorer with increasing elevation, cooler temperatures and increasing duration of snow cover.

The area is biologically rich, but the numbers of species present are well quantified only for vertebrates. Streams and lakes host about 26 species of fish, 13 of which are anadromous. Although more species are present within the area, about 180 terrestrial vertebrates use forests for breeding or as important wintering habitat.

Social and Historical Context

About 75 percent of the management area is public land, where public concerns must be addressed far more rapidly and directly than on private land. Much of the region is coastal temperate rainforest, which may be the most controversial forest type in temperate regions. Logging natural rainforest has attracted effective environmental campaigns, including boycotts of some forest products (e.g., spotted owl and Clayoquot Sound campaigns).

Because it was the largest company working in coastal rainforest, MacMillan Bloedel (since acquired by Weyerhaeuser) had long been the center of environmental campaigns in British Columbia. These were costly to the forest industry and tended to overshadow efforts to improve practice. In 1997, the company acquired a new chief executive officer (CEO) who wished to explore how the company could move from controversy, and perhaps increase market share, while still harvesting coastal rainforest. Among his first undertakings was to form a team of researchers and practitioners to address the question: Could MacMillan Bloedel stop clearcutting and still regenerate the forest and make a profit? The team collated and analyzed relevant data to determine that it would cost more, but probably could be done effectively. The CEO and Board of Directors concluded the additional cost would be offset by regaining market share and increasing shareholder value. In 1998, MacMillan Bloedel announced it would no longer clearcut coastal forests in British Columbia. To sustain the entire mix of desired values, the company chose to implement variable retention instead of clearcutting and to distribute the variable retention approaches within stewardship zones (which allocate different intensities of harvest).

Although well reasoned (Beese and Zielke 1998, Bunnell et al. 1998), the approach had never been attempted before. MacMillan Bloedel met the challenge of assessing consequences of their new approach by creating The Forest Project. Primary objectives of The Forest Project were to make variable retention operational and create an effective approach to adaptive management. When Weyerhaeuser acquired MacMillan Bloedel in 1999, it embraced those objectives. Sections below describe how this approach to adaptive management was applied.

THE APPROACH

An adaptive management program can be separated into four parts: (1) clearly defined objectives, (2) planning and practices to attain objectives, (3) ways to assess proximity to objectives, and (4) ways to modify practices if objectives are not attained (links to management action). These are described separately below.

Clearly Defined Objectives

We have found it helpful to employ criteria and indicators to guide management. Criteria represent success in achieving desired outcomes within the management plan; indicators represent measures of that success or failure. One challenge was to create an operational definition of biological diversity that would reflect success.

The criterion for success should reflect both scientific and social reasons for sustaining biodiversity. A fundamental scientific reason for sustaining biodiversity is to sustain genetic variability. However, there are no easily definable targets for requisite genetic variability. Moreover, the only self-replicating packages of genetic variability are species and subspecies. These thus represent a measurable, credible, scientific surrogate for the cluster of concepts represented by the term “biological diversity” (Bunnell 1998, Namkoong 1998). Documents originating in the United Nations Conference on Environment and Development 1992 reveal four major public concerns: rates of extinction, future options, productive ecosystems and economic opportunities (Bunnell 1997). Sustaining native species richness connects directly to these concerns. The genetically-based differences among organisms and taxa permit continued adaptability and continued creation of biological diversity (Frankel and Soulé 1981, Mayr 1997). Retaining a variety of individuals and species permits the adaptability that sustains ecosystem productivity in changing environments (Naeem et al. 1994, Tilman and Downing 1994) and also begets further diversity (future adaptability and options), thereby potentially sustaining desirable economic opportunities. Because species represent self-replicating packages of genetic variability and public concerns, we chose native species richness as our criterion of success.

Criterion: Biological diversity (native species richness and its associated values) are sustained within Weyerhaeuser BC coastal tenure.

Indicators beyond species richness are needed to encompass the content of biological diversity and to connect directly with forest planning and practice. We chose three indicators to encompass that content.

Indicator 1: Ecosystems. Ecologically distinct ecosystem types are represented in the nonharvestable land base of Weyerhaeuser’s coastal tenure to maintain lesser known species and ecological functions.

Table 1—Description of stewardship zones[a]

	Zone		
	Timber	Habitat	Old growth
Management emphasis	Timber production	Habitat conservation	Late-seral forest conditions
Portion of managed land base in each zone	65%	25%	10%
Average proportion of productive forest area in reserves	28%	40%	70%
Minimum long-term retention in each cutblock	Dispersed: 5% group: 10%	Dispersed or group: 15%	Dispersed or group: 20%
Primary silvicultural systems	Retention, shelterwood	Retention, shelterwood, selection	Selection, irregular, shelterwood

[a]Adapted from Beese et al. (2003).

Indicator 2: Habitat. The amount, distribution, and heterogeneity of stand and forest structures important to sustain native species richness are maintained over time.

Indicator 3: Organisms. The abundance, distribution, and reproductive success of native species are not substantially reduced by forest practices.

Each indicator assesses different aspects of success in attaining the criterion.

- Indicator 1 assesses ecosystem representation within areas that will not be harvested and is intended primarily to ensure that little known species and functions that may not be assessed by Indicators 2 and 3 are sustained. It also serves to identify unmanaged "benchmarks."
- Indicator 2 complements Indicator 1 by evaluating habitat elements and structures we know are required by many species and projecting consequences of changes in those habitat features through time.
- Indicator 3 assesses whether species naturally present on Weyerhaeuser's coastal tenure are likely to continue as well-distributed, productive populations. It serves as a test of the broader approaches of Indicators 1 and 2.

The indicators and associated measurements encompass much of the complexity inherent in the criterion and necessarily interact. For example, the distribution of ecologically distinct habitat types within the nonharvestable land base of the tenure determines the kinds of habitat provision required in harvestable areas to meet success. Progress assessing major indicators must proceed in parallel because findings for each indicator inform the others. The rationale and measurements for the indicators are discussed by Bunnell et al. (2003).

Planning and Practices to Attain the Objectives

Planning and practices both help sustain biological diversity. Planning removes some areas from active practice (e.g., riparian reserves) and provides context or a roadmap for future stand-level practices. Practices determine local habitat structure. Each is informed by the other. If sufficient structure is retained to maintain species at local levels, structure need not be addressed in broad scale planning. Adaptive management helps provide corrections to the roadmap.

Weyerhaeuser introduced stewardship zones to separate competing objectives to the extent possible. The zoning concentrated commercial harvesting activities, minimized roads, and stabilized economic returns. As well, zoning designated areas with little harvest where organisms adapted to late-seral conditions can remain productive. The company designated three stewardship zones with different intensities of harvest (table 1).

The proportion of land initially allocated to each zone was arbitrary and considered subject to change dependent on feedback from monitoring. The three zones have different goals for both stand- and landscape-level retention of trees to meet their different management emphases (table 1). Full descriptions of the zones are found in Beese et al. (2003); I summarize.

The timber zone is the most extensive and the primary source of economic values. Its primary goal is commercial timber production. Within the zone, up to 80 percent of the productive forest area is available for harvest throughout the harvest cycle. The silviculture system is predominantly even-aged management with retention ranging upward from minimums of table 1. Some sites may receive shelterwood, but all treatments include some permanent retention of structural attributes. Because of its large extent and uncertainty about the outcomes from variable retention, most monitoring occurs in this zone. The name "habitat zone" reflects the opportunity to designate specific practices (e.g., retention type and level) to meet needs of specific species in specific places. Refinements to practice can be implemented as guided by results of monitoring. A full range of silvicultural systems with retention is anticipated in the habitat zone. The old-growth zone is intended to maintain late-seral forest conditions, so relatively little wood is removed. It comprises about 10 percent of the tenure. Within this zone, two-thirds of the forest area is reserved from harvest, and harvest in the remainder is by uneven-aged systems (e.g., group selection or irregular shelterwood with retention). The old-growth zone adds to other unharvestable areas thereby sustaining poorly known ecological functions and meeting the needs of late-successional organisms, particularly those requiring larger areas of older seral stages. Such species may decline significantly or even disappear from the timber zone.

Aggregating the most conflicting values into separate zones reduced local conflict, but was believed insufficient to maintain all forest-dwelling organisms. To retain the kinds of habitat required by many forest-dwelling organisms, the company also implemented variable retention (VR) in all zones (table 1). Variable retention was adopted because it preserves, in managed stands, far more of the characteristics of the natural forest that many of the public strongly value and to which organisms in the area are adapted. Variable retention was first defined and proposed by the Clayoquot Scientific Panel for application in the Clayoquot Sound region of the tenure, and has since been refined by others (e.g., see Franklin et al. 1997 and Mitchell and Beese 2002). The company adopted the terminology to refer to any silvicultural system that ensures that structural elements of the existing stand are retained throughout the harvested area for the long term to attain specific objectives (Beese et al. 2003).

Based on literature assessing forest influence, operational guidelines noted that individual or smaller groups of trees should be no more than two tree lengths apart, and that retained groups of trees should be at least 0.25 ha in area. Within those guidelines, retention could encompass a broad range in amount, type and spatial pattern. Two broad types are recognized: *dispersed* retention throughout a cut block (individual trees or small groups) and *aggregated* or *group* retention (larger groups or patches of trees; fig.1). These two types of retention can be used on the same cut block, and are then referred to as *mixed* retention.

Operational guidelines were not intended to be rules. The variable part of VR recognizes that retention must be flexible in response to many site-specific features (safety, ecological values, silviculture, harvesting feasibility, economics, and visual aesthetics). Moreover, in sustaining biological diversity it is important to avoid doing the same thing everywhere (Bunnell et al. 1999). Under any form of retention, different groups of organisms will be advantaged or disadvantaged. Variability is important to sustain as many organisms as possible.

Within adaptive management, considerations about actions are not limited to what you plan to do to achieve objectives. They include what activities can be modified in the future. Changeable elements of practice are direct links to management and must be a focus of monitoring activities. There are several features of retention that can be modified – amount, patch or group size, type, spacing and ecological features used to anchor patches. Because these features can be modified, they are important elements of monitoring to assess effectiveness. They also specify comparisons that are part of the monitoring design – across levels of retention, across patch sizes (or edge effects), across retention types, or across different kinds of anchor points.

Evaluating Success

Developing the monitoring program to evaluate success is the most intellectually challenging part of adaptive management. I summarize three ideas related to evaluating success: bounding the problem, monitoring questions, and creating structured learning.

We so rarely bound the problem before undertaking to solve the problem that Holling (1978) considered bounding the problem a part of adaptive management. A monitoring problem can be bounded in two broad ways. One is the scope and definition of the problem; the second is the questions that will be asked. Scope and definition were addressed at the outset. Two large issues were the spatial extent of the program and the conceptual extent of biodiversity. The entire tenure of 1.1 million ha was selected as the necessary scale at which the maintenance of biodiversity would be addressed. The conceptual extent of biodiversity was defined by the criterion and indicators.

Bounding the problem eliminates some potential features or organisms as indicators. Our interest in the effects of forest planning and practice on species richness excluded some taxa as effective indicator species. Some species (e.g., salmon, marbled murrelets) spend most of their life at sea and are greatly affected by events at sea where forestry

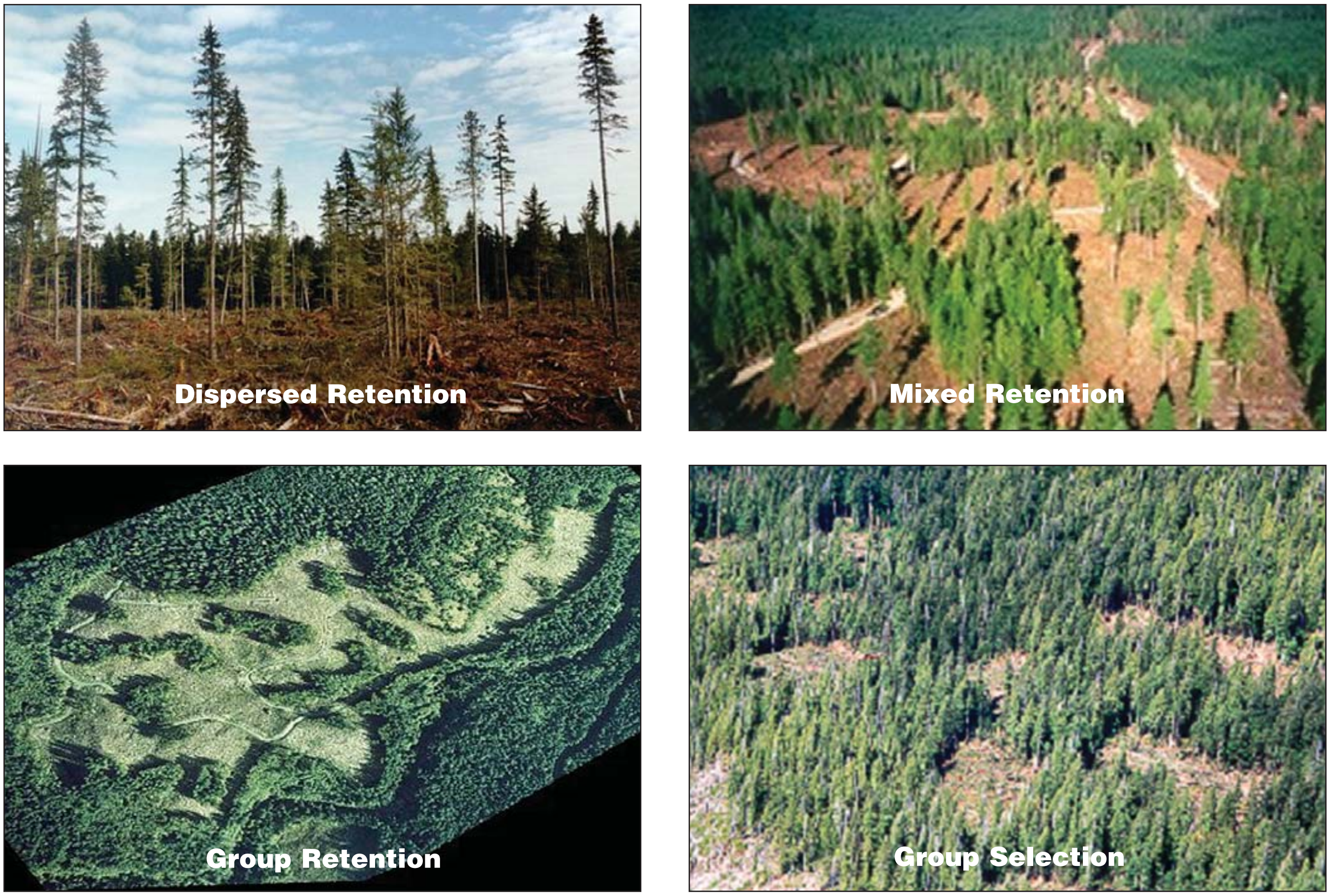

Figure 1—Examples of retention silviculture for Weyerhaeuser's coastal tenure in British Columbia. Groups of trees are no more than 4 tree lengths apart; individual trees are no more than 2 lengths apart.

practices have little impact. Among species restricted to land, some are influenced primarily by features other than forest practices, or their response to forest practices is so poorly known that their response provides no reliable guidance. Bounding the spatial and functional connections of the problem encourages focus on those elements most likely to provide guidance and control.

The process of bounding the problem and the monitoring program is facilitated when the following steps are taken:

- **Determine major issues.** Our issues were to reserve more old growth and implement a harvest system that sustained native species richness.
- **Clearly define objectives and associated indicators of success**. This helps focus the monitoring on appropriate variables. We used a single criterion and three broad indicators of success.
- **Identify the management plan and practices.** The company decided that stewardship zones and variable retention were appropriate for addressing the major issues. The approach to planning and practice became hypotheses to be evaluated by the monitoring process.
- **Bound the problem.** Establish the physical, functional and conceptual boundaries. The goal is to delineate the problem such that extraneous influences over which the manager has little control, and which could mislead monitoring results, are reduced. Some large issues were noted above.
- **Identify the major monitoring questions**. A monitoring design must ask the right questions to reduce statistical uncertainty, properly estimate parameters from noisy data and assign probabilities to alternative hypotheses. Questions selected for monitoring are listed below.

- **Identify data needs.** Although an assessment of current conditions indicates broad knowledge gaps, specific needs must be identified in terms of data best suited to answer the specific monitoring questions.
- **Rank the objectives or questions, and data needs**. Available resources for monitoring are limited. Ranking or setting priorities is critical because it focuses on questions that present greater uncertainty and risks. Questions selected for monitoring should be ranked and assigned to specific objectives. What practices and objectives require immediate attention and are more likely to have an impact on biological diversity? Data needs may then be ranked accordingly.

There is nothing tidily linear about these steps, and the process generally is iterative.

Once the physical and conceptual nature of the problem is bounded, the most compelling questions for the monitoring program can be determined. Monitoring questions depend on the objectives, the practices, and on what we know of the current conditions. They provide a set of hypotheses and direct monitoring to areas where management requires information to adjust activities and avoid unplanned and undesirable outcomes. The link between monitoring and decisionmaking begins with the formulation of an agreement on the monitoring questions.

Uncertainties around management decisions and actions were phrased as questions and winnowed down to 6 major questions. These major questions are stated below in an order that reflects increasingly large areas and longer time frames.

1) What is variable retention providing as habitat?

2) Are there major edge effects within aggregated variable retention?

3) What is the best way of implementing variable retention (e.g., types and amounts of retention)?

4) Is stand restoration effective at creating desired structures and ultimately restoring species distributions or numbers where old growth is rare?

5) Are stewardship zones established in the most appropriate locations?

6) Is biological richness maintained over the tenure, given the mix of zoning, variable retention and operational constraints?

The questions represent the areas of greatest management concern, greatest uncertainty, and greatest ecological risk in implementing the new approach to forest planning and practice. Our ability to answer the questions determines how well the monitoring and modeling program addresses the major issues of managers.

Creating a structured system for learning is critical. Although learning by challenging predictions is fast and powerful, most predictions we can make for biodiversity are nearly trivial. Comparisons, however, are powerful ways to learn. Some comparisons are obvious – those involving changeable practices (e.g., amounts and type of retention). In most instances, it is possible to discern which member of a comparison is more or less effective (but see Bunnell and Dunsworth 2004). Targets, such as natural disturbance regimes, provide more equivocal guidance because society rejects the entire range of natural disturbance or the regime is difficult to quantify (e.g., Agee 1993, Cumming et al. 1996). We chose most of our comparisons from changeable practices. They determine how we intend to acquire knowledge. We used literature review and pilot studies to determine what indicator measurements to use in making comparisons. The what and the how are summarized in a cross-design matrix (Kremsater et al. 2003: table 3).

The cross-design assigns the broadest array of indicators to comparisons that are the highest priority or involve the most pervasive practices. As well, it permits assigning the most critical biodiversity indicators to several comparisons, enabling some commonality of evaluation. Priorities are based on literature review and pilot studies, and permit thoughtful scaling back if budgets decline. Stratification and blocking are necessary within the design to permit effective scaling up to larger areas. Most comparisons are focused on common operational practices that are amenable to change. Experimental studies are used to extend the common range of practice, ask specific questions, or when pretreatment measures are revealing (e.g., slowly changing variables with high spatial variability). Experimental studies also permit more detailed evaluation of some mechanisms that permit scaling up or projection through time.

Closing the Feedback Loop

Linking findings of monitoring to changes in practices closes the loop in adaptive management. A fundamental question when developing any monitoring program is: What would we do with the data if we had them? New information collected by the monitoring program for adaptive management is of little use to practitioners if it does not link to management practice. Linkage is provided by both the evaluation system developed for each indicator, and by descriptions of potential management actions that are expected to help correct any failures (e.g., Bunnell et al. 2003). The most frequent cause of failure in adaptive management is the lack of subsequent action based on findings of monitoring (Lee 1993, Ludwig et al. 1993). Ability to change may require a formal mechanism for accepting results and associated management or policy changes. For this reason three new structures were invoked within the overall strategy.

The Adaptive Management Working Group is composed primarily of researchers, including academics, consultants, company employees, representatives of companies with adjacent tenure and government representatives. This group's charge has been to design the adaptive management approach and associated pilot studies, and refine the concepts and scientific portion of the Coastal Forest Strategy. The Variable Retention Working Group is composed of practitioners who are responsible for the innovation and practicality required to make the new practices work. Links between these two groups helps ensure that scientific findings do feed back to management action. The International Science Panel provides credibility through quality control and guidance from a breadth of experience. The Panel also helps evaluate the credibility of any findings of the monitoring program that are contrary to existing policy or regulations. The issue of managing to sustain biodiversity is value laden and must connect with (and perhaps influence) government regulation and policy. Each group has been critical to making the process a success.

Brief examples for each major indicator illustrate closing the loop. Management responses to analysis of Indicator 1 (ecosystems) already have occurred. Old-growth zones initially were delineated in a few large, contiguous areas. A few were reallocated to improve both ecosystem representation and increase alignment with areas of public concern. The main weakness within nonharvestable areas (under-representation of drier/warmer variants) was identified and stimulated two actions: a pilot restoration program to develop old-growth characteristics in riparian zones of the northeast and west side of Vancouver Island, and an economic analysis of the costs of applying the program elsewhere (e.g., southeastern Vancouver Island). Evaluation of Indicator 2 (habitat) suggested no strong corrective measures, but helped encourage the reduction of dispersed retention and increase in mixed retention initially inspired by operational reasons. Indicator 3 (organisms) affirmed those actions. For example, songbird responses suggested little difference from natural benchmark sites for group and mixed retention once amounts of retention attained 20 percent. More details on management response are found in Bunnell and Dunsworth (2004).

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Long-Term Studies: The Basis for Science Based Resource Management

Jerry F. Franklin[1]

INTRODUCTION

Long-term observations are essential elements in the science and application of resource management. Regardless of how attractive and sound they appear, theories, models, and management prescriptions ultimately are nothing but untested hypothetical constructs until they are validated by scientifically (including statistically) credible observations made in the real world.

The ecological science used as a basis for much of our management is largely composed of theories, often (mostly?) untested (Franklin 1989). The long-term nature of much of the relevant ecological science—such as the responses to disturbances and patterns in stand development that occur over many decades or even centuries—make validation particularly challenging. Empirical data on the long-term ecosystem responses to our manipulations are imperative. Some of the necessary data can be collected as a part of carefully designed monitoring programs, but scientific experimentation also needs to be part of the validation process. Indeed, there are circumstances where monitoring can only be effectively accomplished by conducting a carefully designed experiment (Franklin et al. 1999a).

ESTABLISHING LONG-TERM STUDIES

There are some important issues associated with the development of long-term experiments designed to test theoretical constructs and management hypotheses. First, the number of these experiments will be limited because of the difficulty and expense associated with establishing and maintaining long-term experiments in forest responses. Hence, such experiments need to focus on major paradigm shifts, such as fundamental changes in silvicultural practices. The Demonstration of Ecosystem Management Options (DEMO) experiment established in the Pacific Northwest during the last decade meets that criterion with its focus on structural retention as a part of regeneration harvest practices.

Second, these experiments need to be as robust as possible, since there are not going to be very many of them. An important principle in making them robust is keeping the designs relatively simple or clean. This is sometimes referred to as the KISS principle: Keep It Simple Stupid! Foresters often try to incorporate too many variables in the same experiment, which almost invariably results in insufficient replication and often in confounding among variables. Confounded experiments, where multiple variables are simultaneously altered, seem to be a particular favorite of silvicultural researchers with their focus on "silvicultural systems" rather than fundamental variables, such as effects of tree spacing and density on forest responses.

These issues also relate to the second KISS principle (KISS II)—Keep It Statistically Sound. Independence among experimental variables (i.e., avoiding confounding), strong contrast in selected levels of variables in the treatments (as opposed to small incremental changes), sufficient replication, random assignment of treatments, and untreated controls are all elements in addressing KISS II.

The development of the DEMO experiment exemplifies the difficulties of dealing with these issues (Franklin et al. 1999b). The initial design provided for a range of tree retention from 0 to 100 percent but this was confounded with the pattern of tree retention. The ultimate design was

[1] Professor, College of Forest Resources, University of Washington, Seattle, WA 98195, USA. Email: jff@u.washington.edu

primarily a 2 X 2 factorial design providing for a clean comparison of retention levels (15 and 40 percent) and spatial pattern of retention (dispersed vs. aggregated).

Data management is another major challenge in long-term research. Sufficient resources need to be available to provide for quality control, data documentation (metadata), and archiving/accessing. Researchers invariably want to economize in this area, which is a serious and potentially fatal mistake. Experience with the National Science Foundation's Long Term Ecological Research program indicates that about 25 percent of the budget needs to be allocated to data management. Fundamentally, the question is, Are the data worth collecting or not? If they are, then they must be adequately managed or their value will be lost.

Obtaining sufficient resources and organizational commitment to sustain long-term research (experiments) and monitoring is probably the greatest challenge. Most organizations—governmental and otherwise—operate on the basis of annual budgets and in an environment of constantly changing priorities. The emphasis is ever on the short term. About the only way of assuring long-term support may be creation of a trust or endowment for long-term studies, an approach with which few organizations are experienced or inclined. The Nature Conservancy is one organization that has created endowments for funding of long-term monitoring programs.

Finally, committed individuals are critical to long-term research. Champions are needed to get such programs established to carry them forward (Strayer et al. 1986). Unfortunately, these individuals often suffer a professional penalty since most reward systems do not adequately recognize the value of such contributions.

CONCLUSION

In conclusion, long-term studies are absolutely essential to scientifically-based resource management. The challenges to successfully conducting long-term studies are immense, however, including the difficulty of finding and sustaining the necessary resources. Organizations involved in research and management of natural resources, particularly the USDA Forest Service, were critical in developing and supporting long-term research during much of the 20th century; we need to remember these roots and reaffirm our commitment to this scientific infrastructure.

In developing long-term experiments:
- Keep them simple
- Keep them statistically credible
- Think outside the box (or at least beyond it)
- Devote the necessary resources to data management
- Build the capacity for sustaining the long-term studies (e.g. establish trusts, publicize the studies to provide recognition or "profile", and "leave footprints" for future generations.)
- Provide leadership

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Forest Management: Science-Based and Understandable

Klaus von Gadow[1] and Christoph Kleinn[2]

ABSTRACT

The objective of forest research is to reach a better understanding of biological and economic systems and to generate information that is useful for management. An important objective of forest management, on the other hand, is to use this information, but this is not a trivial task. These two objectives are not always easy to match in an increasingly fragmented scientific environment which rewards highly specialized investigation. This paper presents a simple concept that is capable of matching the objectives of forest research and management. It is often postulated that forest management should be sustainable, based on validated research results, conform to acceptable environmental standards, and understandable to the public. These objectives may be difficult to achieve, but it may be possible to come within reach of them if the following requirements are met:

1. A variety of forest development paths are designed and evaluated by different scientific disciplines,

2. Management activities are effectively monitored in the field,

3. Forest management practices are understandably demonstrated in the field.

Based on these assumptions, a practical framework for science-based management of a forested landscape may include three elements. These elements are presented here under the three headings: forest design, research and demonstration, and harvest event analysis. We will first give a brief overview of forest management systems, then discuss different types of field experiments and finally show how research and management can be linked. This concept can be used to make accessible at least some of the wealth of information that is available within an increasingly specialized and fragmented scientific landscape.

KEYWORDS: Research and demonstration, designing forest development, harvest event analysis.

INTRODUCTION

The initial theoretical basis for sustainable forest management was established during the early 19th century by scientists who developed the principles of sustainable harvest control and discounted cash flow analysis (Faustmann 1849, Hundeshagen 1826). Empirical yield data were needed to apply these general theories in concrete practical situations. Such data were derived from long-term growth and yield studies or provenance trials (Pressler 1865, Schwappach 1890, Spellmann and Schober 2001) and used to develop flexible growth models for different levels of resolution (Burkhart 1987, Ek and Monserud 1974, Gadow 1984, Pretzsch 2001). The growth models are essential tools for evaluating future treatment options for complex forest ecosystems. Evaluating treatment options has become a nontrivial task because societies demand integrated and wide-ranging approaches to forest management that address social, ecological, and economic goals. The matter is further complicated by the fact that the demands of society are not constant. The objectives of forest management are not only numerous, they are continually changing.

[1, 2] Institute of Forest Management; Georg-August-University Göttingen, Büsgenweg 5, D-37077 Göttingen, Germany.
Email for corresponding author: kgadow@gwdg.de

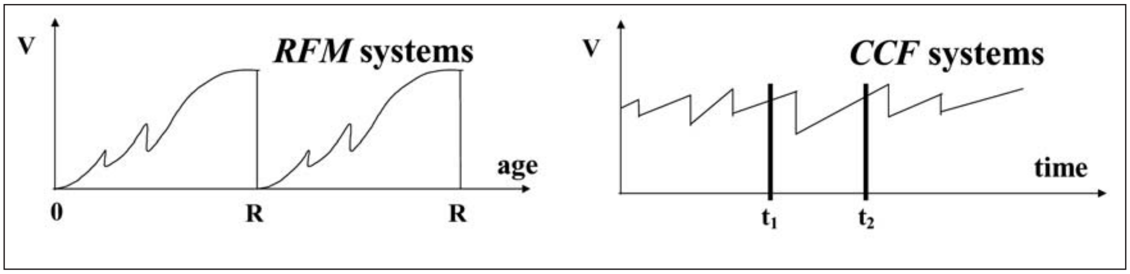

Figure 1—Development of biomass (v) over age or time for two archetypical systems of forest management: rotation management systems (left) and continuous cover forestry systems (right).

The objective of forest research is to reach a better understanding of biological and economic systems. Management needs to utilize this understanding, but this is not a trivial task. This paper focuses on matching the objectives of forest research and management. We present a science-based forest management concept which includes three elements: an approach known as forest design, a system of field research and demonstration, and a monitoring concept which is known as harvest event analysis. We will first give a brief overview of forest management systems, then discuss different types of field experiments, and finally show how research and management can be linked. This concept can be used to make accessible at least some of the information that is available within an increasingly specialized and fragmented scientific landscape.

FOREST MANAGEMENT SYSTEMS

Forests represent a remnant wilderness with high recreational value in densely populated information societies, a natural resource threatened by elimination in impoverished regions, and a renewable reservoir of essential raw materials for the wood-processing industry. Approximately 2908 million ha or 23 percent of the continental surface has been classified as productive forest and subdivided by Solberg (1996) into 5 categories of forest management. By using a somewhat simplified classification based on the development of timber volume over age or time, two archetypical types of sustainable forest management[3] system may be distinguished (fig. 1).

Rotation forest management (RFM) systems with fast-growing timber species and intensive silviculture are found in the Southern Hemisphere (Chile, South Africa, Australia, New Zealand), the southeastern United States, many parts of Asia, and the Mediterranean region. According to Cossalter and Pye-Smith (2003), the increase in human population and economic development in most countries result in a continuously rising demand for wood. Wood is currently the fifth most important product traded worldwide. Vast quantities of wood are harvested to provide fuel, fibers (pulp, paper products, board), sawn timber and veneer (construction, furniture, packaging) and raw material for a future "ligno-chemical" industry. It is estimated that an extra 100 million ha of cultivated forests will be needed by the middle of the 21st century to satisfy the potential future demand for wood. At the same time, there are serious concerns about the sustainability of cultivated forests and their perceived low resistance to disturbances such as storms or pest outbreaks. Monocultures are generally viewed in a negative light in connection with biodiversity conservation, and there is a need to address these concerns and to identify potential risks associated with plantation forestry (Cossalter and Pye-Smith 2003).

Continuous-cover forest (CCF)[4] management systems are characterized by selective harvesting and are most frequently found in densely populated industrialized regions and in some tropical forests. In CCF management the stand age is undefined and forest development does not follow a cyclic harvest-and-regeneration pattern. Instead, it oscillates around some "ideal" level of growing stock. Harvest control is based on some ideal diameter distribution (Guldin 1991, Laughton 1937, Leak 1964, Meyer 1933, Mitscherlich 1952, Schütz 1994, Susmel 1980, Virgilietti and Buongiorno 1997). The mean annual increment is not appropriate for

[3] Nonsustainable forest management is characterized by sporadic exploitation (without regeneration) of a forest resource which contains some trees that are considered worth harvesting.

[4] The terminology is not always clear: CCF management is characterized by selective harvesting and the use of natural regeneration; selective harvesting techniques are also practiced in the so-called "near-natural forest management," favoring site-adapted tree species and some kind of "natural forest management."

measuring productivity and the traditional sustainability criteria, such as the normal growing stock, are not applicable. Considerable forest areas in Europe and other parts of the world are currently being converted from RFM to CCF systems (Pommerening 2002, Spellmann 1998). A consequence of the conversion policy is that particular emphasis is placed on specific silvicultural methods to facilitate the transition from clearfelling systems to "near-natural" forest management. Continuous-cover forestry systems are often preferred by private forest owners because of cost savings for planting or tending operations and a potential for a high-value increment of certain tree species. Continuous-cover forestry systems are also attractive for public forest administrations in regions where environmental concerns and habitat conservation are important issues (Otto 1994, Pommerening 2001, Sturm 1995).

FOREST FIELD EXPERIMENTS

Credible forest management is based on empirical research, and the aim of the early field experiments established during the 19th century was to measure timber yields on different growing sites in response to specific thinning treatments. Some of these experiments have been remeasured for over a century, providing valuable information on long-term developments (fig. 2, Pretzsch 2001).

The value of information to be gathered in forest experiments has to be weighed against the estimated cost of collecting it. Not only are the available resources limited, but time is also a major constraint. Furthermore, the validity and effectiveness of an experiment is influenced by its design and execution. Thus, attention to the planning of field experiments is important. We may distinguish manipulated experiments and observational studies.

Manipulated Experiments

A manipulated experiment is an investigation that establishes a particular set of circumstances under a specified protocol with the aim of testing a hypothesis. The adjective "manipulated" implies the establishment of a set of predefined treatments which allows comparison of the effects or responses resulting from these treatments (Cox 1958, Fisher 1935). Thus an experiment deliberately imposes a treatment on a group of objects in the interest of observing the response. A typical example of a manipulated experiment is the *Pinus radiata* study at Glencoe Hill in South Australia. Beginning in 1985, five sites were established across a range of ages, soil types and stand productivity. Each site was established with four replicates of plots representing

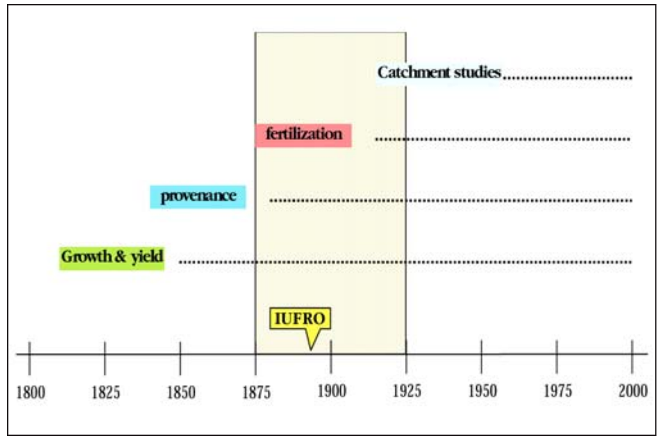

Figure 2—Diagram showing the development of different types of forest field experiments (after Mårell and Leitgeb 2004). Growth and yield studies evaluate tree growth, provenance trials the suitability of certain species to given site conditions; fertilization trials the effect of fertilizer applications to tree growth, and catchment studies the effects of afforestation on the water yield. The International Union of Forest Research organizations (IUFRO) is an international network of scientists involved in studying trees and forest ecosystems.

3 thinning and 12 fertilizer treatments in a 3^1 x 4^4 factorial design. The objective was to evaluate differences between thinning and fertilizer treatments, where they existed. The establishment of the experiment necessitated finding large sites of at least 70 ha which were relatively homogeneous in terms of age, site quality, soil type and stand density. The choice of sites that met all these criteria was extremely limited (O'Hehir 2001). Another example of a manipulated experiment conducted in the Northern Hemisphere is the Roof Project established in the Solling Hills of northern Germany. The aim of the Roof Project was to evaluate the effects of changes in environmental conditions on a Norway spruce (*Picea abies*) ecosystem, based on manipulated input of nutrient and water supply (Dohrenbusch et al. 2003). The roof experiment consists of 4 plots, a control plot (D0); a clean rain roof (D1) where the precipitation is demineralized and subsequently enriched with sodium hydroxide and a nutrient solution that is applied to the ground under the roof; a control roof (D2) where the precipitation is not modified; and a drought/ rewetting roof (D3) that is used to simulate drought conditions. There are many examples of such manipulated field experiments. Depending on their scope, their establishment and maintenance may be very costly because—particularly in silvicultural and growth-and-yield experimentation—relatively large experimental plots and relatively long time periods are needed (Kleinn and Köhl 1999).

Some of these experiments are remeasured for more than a century. A particularly interesting example of a long-term field study is the CCT[5] spacing experiment established in South Africa during the 1930s by A.J. O'Connor (Gadow and Bredenkamp 1992: 55). Most of the CCT experiments consist of 9 to 18 plots each covering 0.04 ha, sometimes with up to 4 replicates. The basic series includes 9 plots, representing a range from extremely low to very high densities, and thus provides answers to such fundamental questions as the maximum density that can be expected on a given site, or the relation between stand density and biomass production. Selection and definition of sites for manipulated experiments is usually a directed selection following criteria of homogeneous conditions and minimum size. It is not a randomized selection as used, for example, in forest inventories.

Comparative Observational Studies

A controlled experiment deliberately imposes treatments on experimental plots with the aim of observing a particular effect/response. This differs from an observational study in which the actual status of a population is to be assessed. A hybrid type of study is the comparative observational study which involves collecting and analyzing data from different site conditions but without actively predefining or changing these conditions, i.e., without applying treatments (Kuehl 1994). There are manifold examples of comparative observational studies in forestry and in other disciplines. Typical in forestry are tree growth plots established on sites with different growing conditions to evaluate specific growth patterns in response to the observed conditions at the beginning of the growth period. The treatments (different site conditions) are not imposed and controlled by the researcher. Examples are the experimental growth and yield plots in Malaysia described by Teng (1999). The ultimate aim of these studies is *external validity*, the ability to generalize from a limited set of observations. No one is interested in observations that cannot be extended beyond the particular restricted set of available data, but the ability to generalize depends on whether the observed response measurement is a representative one. We need to clarify whether the study sites were a representative sample and whether the results of the observations may be legitimately extended to the relevant general population. Helpful in this regard is a comprehensive description of the study sites and of the methodology that was used, so the reader can judge whether the results are applicable to a particular situation.

Comparative observational studies are also known as quasi-experiments (Campbell and Stanley 1963, Cook and Campbell 1979). One reason for doing quasi-experimental research is to capture a sufficient number of different conditions. The intention may be to observe changes in tree growth and to attribute these changes to some variable such as the development of air temperature or carbon dioxide concentration over time. Observational studies tend to involve many different and interacting relationships between variables, and it often happens that much of the variability cannot be explained by the available observations. Statistical inference from these studies should be interpreted as "testing differences between different conditions" and not as "testing effects" unless further evidence (external to the experimental study) points to the existence of a cause-effect relationship. However, observational studies are carried out on a default basis in most regions, such as forest management inventories to support forest management planning and large area forest inventories to support forest policy formulation. It is, therefore, highly desirable to use those data also to analyze cause-effect relationships and to test hypotheses (such as the relationship between forest health status and proximity to industrial facilities, or the relationship between site conditions and tree growth). Schreuder and Thomas (1991), in an excellent paper, discuss the methodological implications when using forest inventory data to establish cause-effect relationships.

Due to lower maintenance costs, observational studies have become very important during the past decades. They may be classified as long-term, temporary, and interval studies. A disadvantage of long-term studies is the high maintenance cost of the research infrastructure and the long wait for data. The object of the trial is not always achieved because plots may be destroyed prematurely by wind or fire. Temporary plots, also known as chronosequences, are measured only once but cover a wide range of ages and growing sites. Thus, the sequence of remeasurements in time is substituted by simultaneous point measurements in space. This method has been used extensively during the 19th century (Assmann 1953, Kramer 1988: 97, Wenk et al. 1990: 116). Chronosequences may provide information relatively quickly, but they do not capture rates of change in response to a known initial state. A compromise may be achieved by using a system of observational studies, or interval studies, which maintain the advantages of permanent (change rates) and temporary plots (broad coverage of initial states and minimum wait for data). Interval plots are

[5] CCT means "correlated-curve-trend" and refers to a particular way of describing the effect of stand density on tree growth.

measured at least twice. The interval between the measurements is sufficiently long to absorb short-term effects of climatic fluctuations (for details, see Gadow and Hui 1999).

Multidisciplinary Forest Ecosystems Research Networks and Platforms

Many of the more recent forest field experiments have become multidisciplinary in scope. The silvicultural treatments employed in these experiments are designed by teams which include scientists with different backgrounds and traditions. These studies represent major investments, and their objective is to meet increasing public demands for forests that provide healthy environments for people, support biological diversity, and sustain economic productivity (Peterson and Monserud 2002). Several research networks have been established with the aim of providing data for projects, research units and experts dealing with forest ecosystem research. An example was the European forest ecosystem research network (EFERN) initiative which was funded by the European Commission (ifff.boku.ac.at/efern). From 2001 to 2003, the European network for long-term forest ecosystem and landscape research (ENFORS) conducted a survey of valuable forest field research and monitoring facilities (see www.enfors.org). Most of the forestry research networks were created during the past 20 years, mainly in response to the air pollution and forest dieback issues (see Mårell and Leitgeb 2004).

LINKING FOREST RESEARCH AND MANAGEMENT

It is often postulated that forest management should be sustainable, based on validated research results, conform to acceptable environmental standards, and understandable to the public. These objectives may be difficult to achieve, but it may be possible to come within reach of them if the following requirements are met:

1. A variety of forest development paths are designed and evaluated by different scientific disciplines,
2. Management activities are effectively monitored in the field,
3. Forest management practices are understandably demonstrated in the field.

Based on these assumptions, a practical framework for science-based management of a forested landscape may include three elements: forest design, research and demonstration and harvest event analysis.

Forest Design

Forest planning can reduce uncertainty in management outcomes by anticipating the future in a systematic way, thus reducing the likelihood of unexpected events. It can also improve the likelihood that future developments will agree with specified objectives. Forest planning requires tools that are understandable and easy to use, support a negotiation process, and can assist in reaching widely acceptable decisions relating to the management of trees and forests. The Multiple Paths Model is one such tool. This model assumes that a forested landscape is an aggregation of spatially defined land parcels of different sizes and shapes, that each parcel is characterized by a specific tree population with a given set of attributes, that multiple development paths are available for each individual land parcel, and that each path has a value.[6] This theory and its technical implementation can be used in any managed ecosystem with any set of objectives; it is spatially explicit, combining stand-level objectives and landscape-level constraints. This concept is easy to understand. It provides an excellent basis for incorporating knowledge from different scientific disciplines (see applications by Bettinger et al. 1997, Chen and Gadow 2002, Öhman and Eriksson 1999).

The Multiple Paths Model represents a generic theory of forest development which is suitable for any arbitrary silviculture. A scenario for a forested landscape as a whole is a specific combination of management paths in all the individual land parcels. It is possible to compare the different scenarios and to identify the more desirable ones. The basic approach is well established. An important task is to generate realistic treatment schedules for the different land parcels. A treatment schedule, a path, is uniquely defined by a succession of harvest operations. Each harvest operation is followed by natural growth. A series of paths can be generated by using a growth model and a thinning model. A thinning model is an algorithm which translates the adjectives used by foresters to describe a harvest operation (high/low/heavy thinning) into a specific protocol which identifies the trees that will be removed. Examples of such thinning models are given by Albert (1998) for beech forests, Staupendahl (1999) for spruce forests and Rautiainen (1999) for a dipterocarp forest. Different thinning types, applied during successive periods, generate a variety of development paths, each representing a unique treatment schedule

[6] A path is characterized by a specific succession of management activities followed by natural growth.

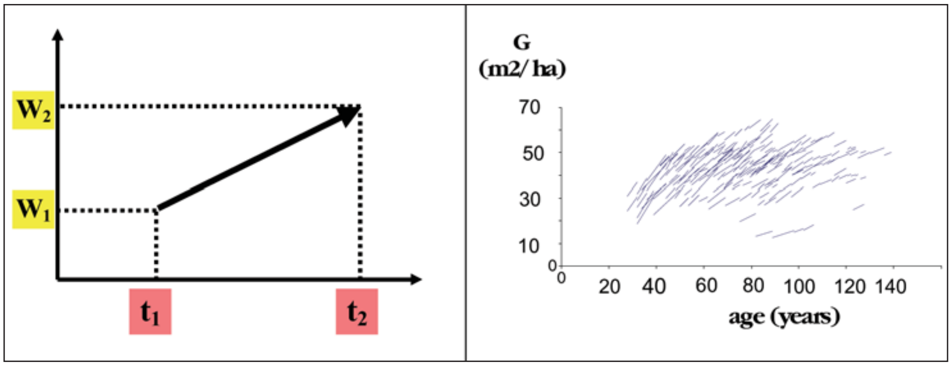

Figure 3—An important objective of a research and demonstration area is to measure change rates of certain variables (W) per unit of time (t) in response to a given set of conditions at time t_1 (left). The change rates provide a basis for generalizations, for example about the basal area change rates in response to a given initial basal area and age (right).

for a given land parcel which can be evaluated and compared with other schedules, based on the experience of various scientific disciplines.[7]

Research and Demonstration

The ultimate objective of forest research is to generate information that is useful for management. An objective of forest management, on the other hand, is to use this information. These two objectives are not always easy to match in an increasingly fragmented scientific environment which rewards highly specialized investigation. A possible solution may be found in the establishment of a system of observational field trials known as research and demonstration areas (RDA). As the name implies, the purpose of a RDA is to gather empirical observations about the resource and at the same time to present the information to an interested audience (fig. 3).

Based on the work by Nöllenheidt (2000) for example, a research and demonstration area in Europe may represent the core area within a management demonstration forest covering only a few hectares. Roschak (1998) assessed the diameters, heights, and position coordinates of all trees within such an area. These data provide detailed information about the species, size distributions, and the spatial structure, as well as the changes caused by a harvesting operation. Assessments are not limited to one discipline. Thus, RDAs can be used to obtain comprehensive empirical data about forest development in response to specific treatments. These areas are particularly useful for education and training. The size of an RDA is often related to the operational areas required by forest management. For example, although large plots are more common in North America, small areas may be more suitable in Europe where forestry is practiced on a smaller scale. Interval plots, measured twice and spread over a range of growing sites, development stages and silvicultural treatment categories, combine the advantages of the permanent plot (change rates) and the temporary plot (minimum wait for data).

Harvest Event Analysis

A harvest event involves a drastic modification of many forest conditions, and foresters are not always aware of the consequences (Zucchini and Gadow 1995). It is not only possible, but also quite simple and logical, to combine the activities of management monitoring and resource assessment. This combination may be achieved by timing the assessment so that it coincides with a harvest event. Most resource assessment activities are scheduled to take place at regular intervals (causing the data to become invalid after the next harvest) or immediately after a harvest (to evaluate the damage done by the harvesting activities). A harvest event assessment captures stand data immediately after the trees have been marked for removal but before they are cut. Thus information is available about (a) the forest condition before harvesting, (b) the removed trees and (c) the forest condition after the harvest. A harvest event analysis can then be employed to evaluate the management-induced changes to the ecosystem. The removal of a tree modifies the spatial distribution of the temperature and radiation and influences a variety of biogeochemical

[7] Further details of the constrained optimisation approach may be found in Clutter et al. (1983), Gadow and Puumalainen (2000), Lappi (1992), Pukkala et al. (1995), Ware and Clutter (1971).

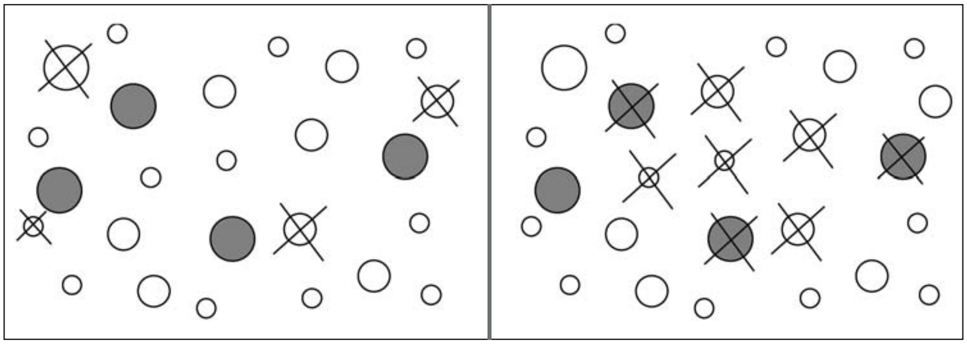

Figure 4—A harvest event may be evaluated in terms of a change in forest density, forest structure and forest value. The diagram shows a hypothetical forest section which may be modified by a harvest event in different ways; different shadings represent different tree species, crossed trees are marked for harvesting.

processes. Thus, harvest events may be evaluated in terms of a change in forest density, forest structure and forest value (fig. 4).

A harvest event analysis was done countrywide in South Africa during the 1970s and 1980s. The method, which was then known as "thinning control," involved a systematic sampling in all units that had been marked for thinning. The analysis involved a quantitative evaluation of the economic effects of a pending thinning operation, *before* the operation would be carried out. It proved to be a very effective method of preventative control and comprehensive monitoring.

For several years, harvest event analysis has been an important part of the curriculum at the Forestry Faculty in Göttingen, Germany. A harvest event is an ideal opportunity for bringing together various disciplines. The basic event analysis, involving modifications of forest structure and growing stock value, is complemented by an evaluation of the effects of a particular harvest operation on the soil conditions, the habitat quality relating to a variety of organisms, the genetic structure of the tree population, and the forest microclimate. The method is specifically appropriate in uneven-aged, multi-species forests managed in the selection system where the multiple effects of a particular harvest operation are not always immediately evident.

CONCLUSIONS

A managed forest ecosystem may be seen as an enterprise which produces a comprehensive set of goods and services and which constantly needs to adapt its production processes and its range of products in response to an evolving market. This objective can be achieved if research is made accessible at different levels, as in other enterprises. Thus, it is often postulated that forest management should be sustainable, based on validated research results, conform to acceptable environmental standards, and understandable to the public. These objectives may be difficult to achieve, but it may be possible to come within reach of them if the following requirements are met:

1. A variety of forest development paths are designed and evaluated by different scientific disciplines,
2. Management activities are effectively monitored in the field,
3. Forest management practices are understandably demonstrated in the field.

Based on these assumptions, a practical framework for science-based management of a forested landscape may include three elements: forest design, research and demonstration, and harvest event analysis. The ultimate objective of forest research is to generate information that is useful for management. An important objective of forest management, on the other hand, is to use this information. These two objectives are not always easy to match in an increasingly fragmented scientific environment which rewards highly specialized investigation.

Figure 5 presents a simplified diagram of a forest management system which is based on continuous research involvement. Designing forest development and analyzing forest events present ideal opportunities for bringing together various scientific disciplines and to utilize their combined experience more effectively.

Research and demonstration areas are used to gather empirical observations, and to demonstrate different management alternatives in the field. Response models which estimate the response of certain variables to a set of initial conditions are obtained in such RDAs. Treatment models

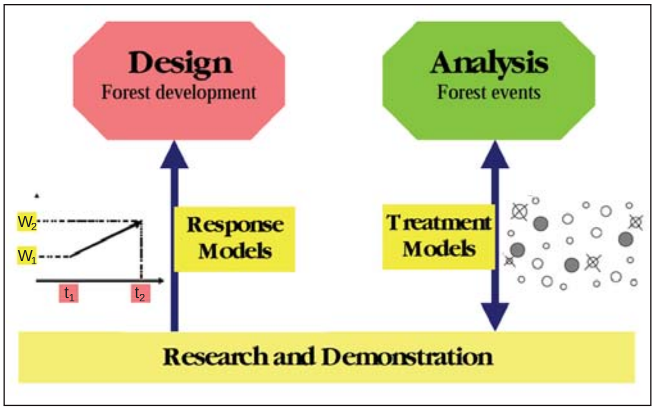

Figure 5—Design of forest development and analysis of forest events are means to ensure sustainable use. Credibility is provided by research and by demonstrating alternative silviculture in the field.

which mimic the modification of forest structure based on a certain forestry vocabulary may also be based on information gained from RDAs, but mainly will be based on harvest event analyses. Both, response and treatment models are essential for generating alternative paths of forest development. The information about the different paths provides the necessary basis for a science-based forest design, which can be evaluated by the different disciplines.

A harvest operation may reduce forest density and modify the spatial structure, the species composition, the ecological conditions for a great variety of organisms, and the value of the standing crop. Harvest event analysis is a method designed to make various effects of a given management activity visible by simultaneously producing information about the forest before a harvest event, the removed trees, and the forest remaining after the harvest event. The analysis thus provides data about changes, which may be evaluated by different disciplines. These data, in turn, are needed for developing growth models, thinning models, and possibly hazard models.

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Long-Term Forest Experiments: The Need to Convert Data Into Knowledge

John L. Innes[1]

ABSTRACT

Long-term forest experiments are a critical part of innovation in the forestry sector. However, most such experiments are challenged for funding and have suffered from the emphasis that some funding agencies are now placing on the provision of short-term results. To be successful, project managers must demonstrate that they can produce both short-term and long-term results. They need to involve interdisciplinary teams in the research, and preferably need to diversify their funding sources to ensure long-term funding stability. Although it is always difficult to change the objectives of an experiment mid-way, researchers need to be aware that priorities change and the relevance of a particular project to societal problems can change.

Many long-term experiments involve the accumulation of large amounts of data. Therefore, a strategy for ensuring the quality and long-term storage of these data is essential. The data need to be accessible to those capable of analyzing the material; these may not necessarily be the same people as those collecting the data. Greater use needs to be made of information management tools such as the Natural Resources Information Network (NRIN) and the Global Forest Information Service (GFIS), as well as ensuring that projects are registered with major international networks, such as the International Long-Term Ecological Research (ILTER) network.

For the results of long-term experiments to be of value to the forestry community, an effective strategy is needed to ensure that the data are converted into knowledge and that this knowledge is conveyed effectively to the end-users. In the United States, this has occurred largely through the extension personnel of the land-grant universities, although these extension specialists have tended to work mostly with the private sector. There is a need to recognize that the potential end-users of the knowledge derived from long-term experiments are varied, and that the means to communicate that knowledge to them will differ accordingly. Traditionally, there has been a reliance on written communications, but other means of communication need to be explored and developed if the full benefits of the research are to be realized. In particular, recent developments in visualization technology are new tools available to the researcher, and greater advantage of these needs to be taken when explaining the future options that research is revealing for particular forests.

KEYWORDS: Information management, research funding, extension, data quality, data management.

INTRODUCTION

Some of the earliest formal experiments in forestry, started in the 19th century, continue today. Most of these long-running experiments are related to growth and yield studies under differing environmental and management conditions and deal with stand-scale experiments. For example, in Switzerland, there are several on-going, long-term experiments that date back to the late 19th century. Trees have been periodically re-measured, and the results have helped develop the scientific basis for the type of silviculture known as "Plenterwald," more commonly referred to in English as uneven-aged forestry (Schütz 1997). Other experiments relate to the development of forested land after

[1] Centre for Applied Conservation Research, Faculty of Forestry, Forest Sciences Centre, 2045, 2424 Main Mall, Vancouver, BC V7W 2W7, Canada. Email: innes@interchg.ubc.ca

disturbance, with the time series from Rothamsted, England, being one of the longest (two small areas were fenced off to observe woodland development in 1882 and 1886) (Harmer et al. 2001). These early experiments and observational studies, virtually all of which come from Europe, are very long term, but generally involve very small areas.

More recent long-term experiments include the watershed manipulations established in North America and involve much bigger areas (Hubbard Brook in the United States is the classic example – http://www.hubbardbrook.org). Experiments at this scale enable the effects of stand and forest treatments on factors such as wildlife species to be determined in a more reliable fashion than is possible in most European experiments. However, very few, if any, of the North American experiments extend more than 50 years. This means that very few studies extend across a whole rotation.

There are also several long-term experiments that have been established in the Tropics, such as the long-term studies at Pasoh, Malaysia (Kochummen et al. 1990). Within this context, it is relevant to mention the large-scale forest fragmentation experiments conducted in Brazil (e.g., Offerman et al. 1995). Some of these are genuine experiments, involving manipulation and replication; others are more akin to case studies. All are potential sources of high-quality datasets that can be used to generate information of considerable value to forest managers, forest policy makers and others.

In all examples, the long-term studies are characterized by the collection of very large datasets. The intention is often to gather sufficient data to assess the impacts of particular forms of management on specific forest values such as water quality and species diversity. However, this intention has not always been successfully achieved. In this paper, I review some of the problems associated with the establishment, continuation and use of large-scale, long-term experiments, with particular emphasis on the need to justify the cost of such experiments through the application of the knowledge that is generated from them.

CHALLENGES ASSOCIATED WITH IMPLEMENTING LONG-TERM EXPERIMENTS

All long-term forest research sites face many challenges. Perhaps the biggest is that although the value of the data tends to increase over time, the risk that the original research question is no longer relevant also increases. Experiments are often set up to test the assumptions associated with a particular practice, but extraneous factors can result in the practice being introduced before the research results become available. Once a policy decision is made, it may undermine the original objectives of the project, making it very difficult for the project manager to justify further funding. For example, as the various forms of variable retention become entrenched in mainstream forest management practices in western North America, comparisons of such treatments with clear-cuts may no longer be relevant. Project managers faced with such a situation need to argue that even when a decision has been made to change practices, it is important to gain scientific understanding of the implications of the change. This is particularly true given that most policy changes occur fairly quickly, generally well before the results of long-term experiments can be expected. With increasing emphasis being given by policy makers to science-based forest management, there is always a need for experiments that demonstrate that such management is in fact based on science.

As policy priorities are constantly evolving, managers of long-term research sites must be sufficiently flexible and innovative to enable their data to be applied to new and emerging problems as they arise, a requirement that may at times seem contrary to the principles of experimental design. For example, the Swiss Long-Term Forest Ecosystem study was set up in the mid-1990s with the specific intention of including both short-term and long-term research (Innes 1994, 1995). The study provides a platform for forest research to be undertaken by maintaining detailed records of meteorology, soil conditions, forest health and other routine observations in a suite of plots across the country. Monitoring data are shared between scientists involved within the project. Individual project scientists can work on a particular problem on one or more of the research sites, on condition that they share their results through publications, extension and other means. The plots, however, are very small (1 ha) and have only one (adjacent) replication, and it will be difficult to make any country-wide generalizations from the results. The small size of these plots also severely restricts the type of study that can be done effectively on the plots, with most studies of larger vertebrates being of questionable value.

Relevance is a critical issue and can significantly affect the possibilities of obtaining funding for long-term experiments. With budgets for forestry research shrinking around the world, increasing pressure is being placed on funding managers to provide financial support for only those projects that are guaranteed to produce results in the short-term. Managers of research funds are under increasing pressure to show “value for money,” and this inevitably is measured in relation to short-term results and impacts. This occurred in British Columbia, Canada, in 2002 and 2003 when the funding agency for forest research (Forest Innovation Investment Ltd.) decided that all research projects had to be completed within a year. As the formal notifications of project success were issued late in both years, the actual amount of time available to conduct the research was considerably less than a year (4 months in some cases). Such a funding policy does not tend to favor long-term research, and even short-term research can be compromised.

Leaders of long-term research studies need to address the tendency to focus on short-term results by examining what data they can deliver in the short term, and what they can better deliver in the long term. For most policy and decisionmakers today, it is simply insufficient to claim that a project will generate exceptionally useful results 30 years from now. Policy works over much shorter timescales, normally reacting to events rather than being visionary or strategic. Consequently, there is pressure to interpret results prematurely, with all the problems that this entails. An important aspect related to this is the need for researchers to demonstrate actively the relevance of their work. It is no longer appropriate simply to publish in the scientific literature and hope that the results will somehow filter through the end-users. An active and aggressive program promoting the results among end-users may be necessary, and researchers need to be aware that there is often considerable inertia in the uptake of new research. Although funding managers believe that it is possible to "measure" the impact of research on management practices or even decisionmakers, this is rarely possible, and attempts to do so may produce spurious results.

It is sometimes easier to establish a new research program than to implement what is already known, and new programs frequently fail to take into account either the policy needs or on-going long-term research experiments. This has happened in British Columbia, where a whole series of new initiatives in the 1990s were inadequately linked to policy and research (Innes 2003). To be successful, researchers, practitioners and policy makers need to work together to identify common priorities. Although this is increasingly happening during the design of research programs, it does not occur frequently enough during the design phase of long-term experiments.

Apart from relevance and funding, long-term forest research faces several other difficulties. Many of these surround the issue of data collection and storage. For example, the rapid development of analytical technologies means that many chemical data are now recorded at concentrations well below the detection limits of early equipment. Automatic data collection and enhanced storage mean that data can be collected relatively easily (such as from automatic meteorological stations). It is sometimes difficult to decide the resolution at which data should be collected and archived, although experience tends to suggest that in long-term experiments, the highest resolution possible is the most appropriate as model calibration and other data needs become increasingly sophisticated. Although storage capacity used to be a problem, data storage capacity today is not a major issue. However, the development of electronic data storage and automatic wireless transfer of data from a collection site to a central repository mean that very large volumes of data are routinely collected. As a result, data handling techniques are continuously changing, and great care is needed to ensure that data are properly archived. Most research institutions have protocols designed to ensure the security of datasets (such as automatic backups and off-site storage of duplicates of data archives). However, where such facilities do not exist, they need to be implemented.

Over long time periods, individual researchers come and go, as do their institutions. Data are frequently lost or corrupted; yet today, there are few excuses for the loss of valuable data. More difficult is the issue of access to those data. Most researchers consider that they have a proprietary right to the data from projects that they are in charge of; yet some, or most, of these data may have been collected by their predecessors. There is always an inclination to hoard data until the opportunity arises to publish the information and, given the current pressures on researchers, this is unlikely to change. However, the collection of another year of data is often a reason that is used not to publish data, and some balance is needed between the needs of the researcher and the needs of the end-user communities. To be effective, the data from long-term research experiments need to be gathered into a relational database and, where possible, access to this database needs to be available through networks (both Intranet and Internet).

There may also be institutional barriers to the development of long-term research projects, even when research funding is available. One issue is the availability of suitably qualified personnel. During the formulation phase, the most important person on the project team is the statistician, but a distressing number of experiments are launched without adequate statistical input. Newly-trained scientists may be reluctant to embark on research that is unlikely to produce publishable results for some time, and here, again, the importance of achieving a balance between the generation of short- and long-term results becomes important. Staffing continuity is also important: although some staff turnover is inevitable and may indeed be desirable during different phases of a project, the abrupt departure of an entire project team could negate years of data collection and associated research.

INFORMATION NEEDS OF FOREST STAKEHOLDERS

It is difficult to judge the information needs of forest stakeholders, just as it is often difficult to identify the stakeholders. In most cases, there is a range of potential stakeholders with an interest in the information. Identifying those stakeholders can be particularly challenging, and converting data into information that is useful to them is even more so. Research that is valued within an academic context is often of little relevance to those with an interest in the research results. In some jurisdictions, effective communication between stakeholders and researchers has enabled the development of research agendas that are relevant. However, there remains an inherent suspicion among some academics that applied research is somehow less worthwhile than "pure" research. Forest scientists need to encourage a change in this view; they need to demonstrate the value of applied research. One problem is the conflict between the needs of those who are likely to use the results and those who provide the funding for the research. Much research funding is reactionary, reflecting the immediate needs of government (or industry) to resolve an emerging crisis or to justify a particular policy. As a result, the research may be designed to provide results that support a particular point of view, rather than addressing long-term, strategic problems through the provision of balanced, scientifically credible information.

A remarkable exception has been the U.S. National Science Foundation, which has provided funding for the Long-Term Ecological Research (LTER) sites (Gosz et al. 1999). The network of sites across the United States has provided the foundation for long-term studies of ecosystem processes, and has avoided many of the problems associated with long-term research. The problems associated with data handling and storage have been dealt with, and the program has been extended beyond the United States (e.g., Barbosa et al. 2004, Su et al. 2001). The sites have provided an important training ground for future natural resource scientists, and the networking opportunities have resulted in strong scientific teams.

The science behind the establishment of long-term experiments can be an impediment to the establishment of good stakeholder relations. Stakeholders may not always be aware of some of the ramifications of particular experimental designs, just as scientists may not be aware of some of the political, social or cultural implications of their work. Early collaboration seems an essential part of developing a strong working relationship between scientists and stakeholders, and neither group should underestimate the time commitment that this could involve. In forestry experiments, scientists must generally work closely with forest managers: many successful experiments arise out of the productive collaboration between scientists and forest managers. There are costs involved for both parties, and unless both are willing to meet these costs, the experiments are unlikely to be successful.

It may be difficult for stakeholders to articulate their needs for information: they do not always know what they want. This position seems widespread in forestry. Bunnell and Kremsater (2003) have argued that there is a greater need for humility among forest policy makers, an argument that must also be extended to forest scientists. A recognition by all of imperfect knowledge may be difficult, but it is essential.

The lack of awareness of knowledge gaps reinforces the need for extension agencies. However, such agencies must move forward from the traditional university–private landowner relationship to include all aspects of research and to extend to foresters in government as well as those in practice. This is particularly important where professional associations have no compulsory program of skills development and continuing education, as in British Columbia.

IMPLEMENTING SUSTAINABLE FOREST MANAGEMENT

A key aspect to implementing sustainable forest management is converting information from long-term forest experiments into knowledge that forest managers and policy makers can use on a daily basis. Within the United States, this is largely a function of the extension services for forest managers and the USDA Forest Service for federal policy makers. However, such services are relatively rare: Canada has no direct equivalent of the extension services mandated by the Morrill and Smith Lever Acts, although the gap in western Canada at least is now being filled by the Forest Research and Extension partnership (FORREX) http://www.forrex.org). In the United States, the Forest Service has also played a major role in making information available, with the Pacific Northwest Research Station (http://www.fs.fed.us/pnw/) leading the way. However, funding managers also fail to consider the importance of extension, generally under

Table 1—Seven actions needed to ensure better uptake of knowledge[a]

• Acknowledge and analyze the complexity of natural resource systems
• Use action research—become actors in the system
• Consider effects at higher and lower scales
• Use models to build understanding and as negotiating tools
• Be realistic about potential for dissemination and uptake
• Use performance indicators for learning and adaptation
• Break down the barriers between science and resource users

[a] Sayer and Campbell 2004

funding extension agencies. This seems to be because many funding body advisory committees are made up of traditional scientists who think that the highest proportion of the budget possible should be devoted to research. The problem is exacerbated by those researchers who fail to budget adequately for extension. The result is that while the quality of the research project may be excellent, the knowledge that is generated fails to reach the people who can use it.

There is debate over the most effective extension techniques. Much depends on the nature of the target audience, and it is increasingly apparent that multiple versions of the same information will have to be prepared if the recipients of that information comprise a range of different stakeholders. Most research scientists do not have the time or the budget to do this, and many do not even go out with managers to explain and demonstrate the significance of their results. This is a major shortcoming of some research projects and one of the reasons why some fail to achieve their desired impact.

Although direct contact with managers on the ground is often the most effective way to see information converted into knowledge, there are experiments around the world that it would be impossible for all managers to see. A way to access the information being generated from these experiments is required. The International Union of Forest Research Organizations (IUFRO) has been involved in the development of an information system that would facilitate access to such information, the Global Forest Information System (GFIS). A prototype of this was launched at the World Forestry Congress in 2003 (http://www.gfis.net), and this year (2004) it has been undergoing an extensive overhaul. With over 60 contributing organizations, GFIS is growing steadily. It is currently concentrating on facilitating access to the "grey literature," but a special project includes developing a major new educational resource. The system has been set up in such a way that it could act as a search engine for long-term data sets and the information associated with these.

The transfer of information to policy makers is more complex, and it is unfortunate that in general, many policy makers have not been receptive to scientific information. Although jurisdictions such as British Columbia claim to have science-based forest management, it is sometimes difficult to see that science. IUFRO has been looking into this problem, having created a task force to address the issue. The task force held its fourth meeting in June 2004, where the results from a number of regional workshops were synthesized, and an attempt was made to identify the critical factors leading to the successful transfer of scientific information to policy makers. Improved methods of interaction between policy makers and scientists are clearly required, and the IUFRO World Congress (http://www.iufro2005.com), to be held in Brisbane in August 2005, is placing special emphasis on this.

More effective interaction between scientists and managers will require several changes in the way that science is practiced. Sayer and Campbell (2004) propose that seven major changes will be required to integrate science with sustainability (table 1), but it is quite clear that the majority of the forest research community is not yet ready to make these changes. Acknowledging the complexity of natural systems is essential, although most science is reductionist in its approach. There is always pressure to provide a "simple explanation," but there is a marked difference between providing a simple explanation and providing an explanation simply. Most stakeholders are unfamiliar with scientific jargon, and explanations that are jargon-free are essential.

The need for action research has been recognized by many foresters. Although this can be interpreted several ways, the adoption of an active adaptive management approach is critical. In this, researchers and forest managers work together to design an experimental approach to new management practices, with adequate controls being used to ensure that any observed impact of a management action can be ascribed to that action. The approach involves a substantial monitoring element which is not only often difficult to fund, but may also be considered as so routine that researchers should not be involved. However, it is widely recognized that projects that practice adaptive management are able to retain their relevance to policy makers better than projects that do not (Guldin 2003).

Considering effects across scales, both higher and lower, is important for long-term experiments. A major weakness of many long-term experiments is that they are often used for research for which they were not designed. Responses are scale-dependent (Innes 1998), and what may be appropriate for one scale may not be appropriate at another scale. There has been a tendency in many long-term experiments to try to use the facility to conduct investigations for which they were designed. For example, censuses of birds are commonly conducted on long-term experimental plots, but many treatment areas are often too small to provide reliable estimates of their use by birds.

The use of models provides the opportunity to demonstrate the likely outcomes of particular scenarios. Models provide an indication of the likely long-term outcomes of particular actions and can "look" into the future in a way that is impossible from observational studies. This is examined in greater detail in the following section.

Many of the difficulties associated with disseminating research results and their subsequent uptake can be related to the methods chosen to communicate the results. There has been a presumption that the most effective means of communication is through the written word. Although this may be true for some audiences, it is not so for all. For example, some groups may have a tradition of oral communication, and this will likely be the most effective way of communicating with them. Even if information is successfully transmitted, there may be no application of that knowledge. A complex suite of factors influence this, but they are beyond the scope of this paper.

Finally, there are numerous institutional barriers between scientists and stakeholders. These range from physical separation to several factors that restrict the ability of scientists to interact with resource users. For example, the reward structures for scientists are often based more on their ability to publish in top scientific journals than on their ability to interact with forest managers and other stakeholders. This can be a significant impediment; not only are scientists discouraged from spending time interacting with forest managers, but they are also discouraged from publishing their work in outlets likely to be seen by forest managers. Again, this is where extension specialists have a role to play.

EVALUATING AND COMMUNICATING THE RANGE OF MANAGEMENT OPTIONS

Evaluating and communicating the range of management options will be difficult. In some areas, such as British Columbia, significant developments have occurred in forest modeling, and ecological growth models have been linked to habitat models and harvest scheduling models, with the results being visualized through computer graphics. This will undoubtedly help stakeholders see the potential impacts of particular choices, particularly those involving trade-offs between different values. Mapping tools are also becoming increasingly sophisticated and may be more familiar to managers. However, as with the publication of results, it seems likely that different techniques will need to be developed for different audiences. Visualization is being increasingly used in education (Fabrika 2003), although there are ongoing debates over the relative advantages and disadvantages of realistic vs. stylized pictures.

Just as there increasing possibilities of visualization, more technology is available that could help stakeholders decide between different options. Adoption of these technologies has been relatively slow, and many of the techniques have been derived from outside the traditional field of forestry. The difficulties associated with the implementation of decision support tools reflects the lack of training that many foresters and forest scientists have had in the "social" aspects of forestry. Interest is now gaining in this area, and it is likely that they will be increasingly applied to the scenarios being produced as part of long-term forest experiments.

CONCLUSIONS

Long-term experiments are invaluable to forestry, but transforming the information generated by them into knowledge that can be used to improve forest management practices is critical. There are many barriers to this, and most managers of long-term forest experiments are devoting so much time to the maintenance of funding for their work that there is little opportunity to address such issues as extension and uptake. This is creating a "vicious circle," as the funding is dependent on the managers being able to demonstrate the value of their experiments.

The conversion of information to knowledge and the dissemination of that knowledge to those who can best use it is a critical stage of any long-term forest research project.

There is a need to better plan for this and to ensure that it becomes as an integral a part of project planning as the experimental design. Whether this can be achieved in the short-term remains to be seen.

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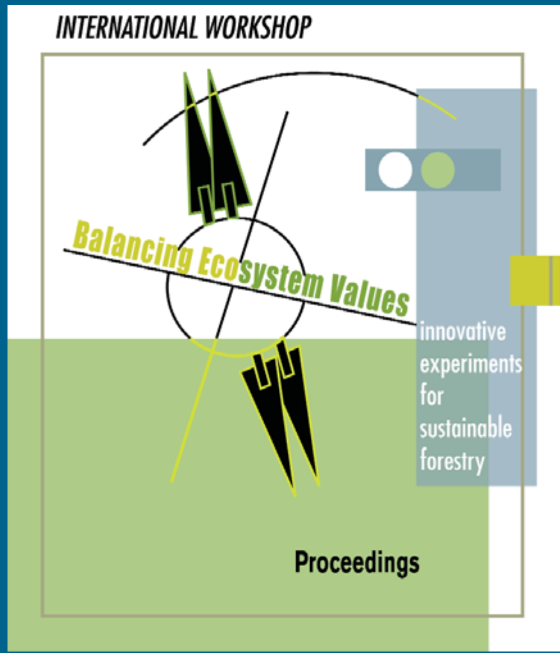
Leslie Brodie and Tim Harrington (both from the Pacific Northwest Research Station) present findings on stand damage and windthrow following partial harvests on the Washington State Capitol Forest. *Photo by Charley Peterson*



REGIONAL EXPERIMENTS

Photo by Tom Iraci

Design Challenges in Large-Scale Management Experiments

Lisa M. Ganio[1] and Klaus J. Puettmann[2]

ABSTRACT

Large-scale management experiments (LSMEs) are implemented at the scale at which management occurs. These studies are typically longer term and include multiple objectives at multiple scales that cover a spectrum of natural resources topics. Designing a study that effectively incorporates these features can be challenging. The initial steps in the design process are prioritizing multiple objectives and identifying primary, secondary and tertiary levels. This hierarchy is used to allocate resources throughout the design process. Each objective implies an associated scope of inference, which in turn is associated with a specific definition of replication. Discussing and coordinating scopes of interest and identifying levels of replication associated with each one are important steps in planning a study. The large spatial and temporal scales in an LSME are a source of large spatial and temporal variation. In an effort to control variation, investigators may initiate changes without considering the effects on the hierarchy of objectives. A structure for acknowledging and planning for these large sources of variation in the design phase is discussed.

KEYWORDS: Large-scale management experiments, study design, multiple objectives.

INTRODUCTION

Recent interest in ecosystem response to management activities has led to the implementation of large-scale management experiments (LSMEs) (for examples, see Monserud 2002). These studies are designed to address management and policy issues at the scale at which management occurs, practically eliminating the challenge to scale up research results to operational activities. However, integrating the work of multiple investigators, each possibly working on multiple objectives, in a single study creates challenges not encountered in traditional research studies (Ganio and Puettmann, n.d.). These challenges, in conjunction with the long-term, large-scale nature of these experiments, have to be addressed in the experimental design and setup. Specific issues include ranking and coordinating research objectives, scopes of interest, choice of response variables, replication and subsampling, treatment definitions, and measurement logistics. It is important to recognize that these components are linked; they cannot be viewed or discussed in isolation, and changes to any one of the components will likely affect the others (Manly 1992).

We propose that dealing with a diverse set of objectives in a single experiment, especially in LSMEs, highlights the importance of proper experimental design; this is necessary to accommodate planning and implementation issues not present in single-objective studies. Experimental approaches used in various disciplines need to be accommodated when multiple objectives (each with its own optimal approach) are combined in a single experiment. This paper discusses study design concepts in this light and highlights statistical and logistical issues that need to be considered in the design of LSMEs.

MULTIPLE OBJECTIVES AND SCOPES OF INFERENCE

The first steps in planning LSMEs are defining and prioritizing research objectives. Generally, the primary

[1] Assistant Professor, and [2] Associate Professor in the Department of Forest Science, 321 Richardson Hall, Oregon State University, Corvallis, OR 97331, USA. Email for corresponding author: lisa.ganio@orst.edu

objective of LSMEs is to document and compare ecosystem response to large-scale management practices over large extents of space and time, e.g., effects of partial overstory removal on bird habitat. But this primary objective can be manifested in multiple secondary objectives that need to be determined and agreed upon. Secondary objectives may include studying effects of large-scale treatments on smaller scaled processes, such as conifer germination or seedling growth as a function of degree of overstory removal. Tertiary objectives may include documenting effects of smaller scaled secondary treatments embedded in the large-scale treatments, such as seedling response to weed control under different overstory densities. Prioritizing multiple objectives becomes the basis for making choices among alternative study design components throughout the experiment.

Even though LSMEs cover large areas, the questions of where and under which conditions results can be used to guide management decisions need to be considered during the design phase of a study (Ganio and Puettmann, n.d.). The scope of inference represents the set of situations to which the results of the current study can be generalized. Replicate units represent the range of variation present in this scope of interest (Hurlbert 1984). As a result of multiple objectives, an LSME is likely to have scopes of inference at multiple scales and thus require replication at multiple scales. A detailed discussion of potential scopes and their associated sources of replication for the various objectives can identify realistic and unrealistic goals. For example, long-term growth response of residual trees to partial overstory removal is not very sensitive to the climate conditions in the spring after the removal. Most foresters would feel comfortable basing management decisions on results from such studies regardless of expected weather patterns. On the other hand, germination of seed may be quite sensitive, and the results from studies in which the overstory treatments were all applied in a single year should only be used to predict germination under similar climatic conditions. Discussions about scopes of inference among all researchers during the planning processes can clarify the extent to which conclusions can be generalized and elucidate necessary modifications of the study design.

Multiple objectives typically cannot be addressed with the same precision in a single study. The prioritization of objectives helps determine how to allocate resources or replications for the study. In an ideal situation, the primary objective requires the most replication so that secondary or tertiary objectives are also adequately replicated. In cases where secondary or tertiary objectives require more replication than the primary objective, however, the experimental design has to be adjusted. For example, to investigate effects of weed control on seedling growth under dense overstory conditions in detail, additional replications could be added in similar, neighboring stands.

The following example demonstrates the interrelationships among the ideas discussed above. Suppose that the large-scale objective is to compare thinning practices on overstory development over 25 years. Six 85-ha units are selected to represent western Oregon and Washington (the scope of inference). A secondary objective is to assess the thinning practices on mushroom production, and a tertiary objective is to compare seedling response to a variety of weed control practices. Mushroom production is highly variable at small spatial scales and from year to year. On the surface this may seem a straightforward study, but a number of specific questions have to be addressed: Will the results from six 85-ha units scattered over two states be able to represent typical mushroom production in western Oregon and Washington in any one year? How might variation among the large-scale units within one year compare to environmentally induced variation at one site from year to year? Will six replicates of mushroom production achieve a level of precision sufficient to detect changes among large-scale thinning practices? Should the scope of inference for the secondary objective be restricted to a narrower set of conditions represented in one large-scale unit while many replications on a smaller scale are used to quantify trends over time? If so, the small replications do not constitute true replications of large-scale thinning. Should investigators look for areas outside this LSME that can be used as auxiliary replicates? These questions highlight how the hierarchy of objectives, the spatial and temporal scopes of inference and replications are all interrelated. Although answers to some of these questions may be unknown, an understanding of these issues is necessary to define the proper study design. In these instances, expert opinion and results from similar studies may be the only sources of information available for consideration.

GENERAL SPATIAL AND TEMPORAL CONSIDERATIONS

Scale can be defined as the extent over which a phenomenon exists and as the resolution at which it exists (Dungan et al. 2002). A scale is associated independently with the process being studied (e.g. the treatment), the observation process, and the analysis. When observation scales (e.g., plot sizes) and analysis scales are not explicitly coordinated, results may not directly address the research question as planned (Dungan et al. 2002). Estimated treatment differences and associated estimates of variation change as observation scales change. Therefore, the design process should include an assessment of the appropriate precision and scale of the observation process (Skalski and Robson 1992). If results of LSMEs are to be compared to other studies, then assessment of the spatial and temporal scales is prudent.

Secondary treatments may be embedded within the large-scale silvicultural treatments in a split plot experimental design. A common example is the comparison of different tree species when planted under thinned overstories. However, embedded treatments may interact in unintended ways with large-scale treatments in time or space. For example, the underplanted seedlings may eventually influence wildlife habitat to the extent that the original large-scale objective (to investigate effects of thinning on wildlife habitat) is compromised. Future problems can be avoided and alternatives suggested if this possibility is considered during the design phase. Embedded treatments do not increase the replication of the large-scale treatment, and care should be taken to identify and avoid pseudoreplication (Hurlbert 1984, Monserud 2002). Scopes of inference for embedded treatments are generally at a smaller scale than scopes for large-scale treatments, and this needs to be reflected in decisions about adequate and appropriate replications for embedded treatments. The issues associated with embedded treatments are complex and discussion of potential long-term consequences among the various researchers in an LSME can identify potential pitfalls that can be addressed in the design phase.

Each research objective has an associated temporal extent (in LSMEs, many of them are long-term), and a timeline along which ecosystem responses are measured. Careful evaluation and coordination of timelines and extents are important for LSMEs when treatment applications or measurements may not occur at the same time for all treatments or sites. An understanding of the temporal variability of response variables is required to make decisions about treatment timing. Experience has shown that treatment applications to large-scale experimental units cannot be always accomplished in the same season or even year (e.g., in the Young Stand Thinning and Diversity Study (Hunter 2001)); therefore seasonal or inter-annual effects may be exhibited differentially on experimental units and objectives. A harvesting delay of a few months may not unduly impact the assessment of long-term tree growth response. But it may be very influential in an assessment of natural regeneration, especially if portions of the unit were harvested prior to seed maturity and other portions were harvested after seeds had dispersed. Effects of measuring experimental units in different seasons or years need to be carefully assessed in the design phase. If treatments were applied in different years, and yearly variation is part of the scope of inference, then measuring replicates of each treatment in different years (e.g., tree growth response 3 years after treatments) is necessary (Monserud 2002). However, measuring different treatments in different calendar years confounds the treatment with yearly variation for some factors (i.e., seed rain or germination) such that the ability to make comparisons is compromised. For these factors, if the goal is to compare treatments in the absence of yearly variation, measuring each replicate of each treatment in the same calendar year is crucial. In the example above, initial treatment definitions may need to be modified to reflect that temporal effects are confounded with treatments. Because an important aspect of LSMEs is the integration of various study components, coordinating treatment timelines is critical to ensure that all necessary response variables are representing effects at the same points in time. Using comparable definitions and resolutions of a response variable over time is important for the same reasons.

SPATIAL AND TEMPORAL EFFECTS ON TREATMENT DEFINITIONS

In long-term experiments, treatments may consist of an initial large-scale application followed by additional manipulations conducted in later years. These follow-up manipulations should be considered carefully. Ecosystem developments after multiple manipulations cannot be attributed solely to the initial application; they are a function of the entire set of manipulations. The decision to use additional manipulations brings up a variety of complex issues. For example, if the initial application resulted in different ecosystem responses in each replicate plot and follow-up manipulations are implemented at the same point in time, then follow-up treatments are applied to different “initial” conditions. Additional variation among replicates may result, making the detection of treatment effects more difficult. Alternatively, if follow-up manipulations are applied to replicate plots within one treatment when specific conditions within those replicates are met, follow-up treatments may not be applied at the same time for different treatments. In this case, treatments may incorporate different inter-annual or seasonal effects that are confounded with treatment effects. During the planning phase of LSMEs, the advantages and disadvantages of these approaches should be clearly laid out and referenced against the hierarchy of objectives before choices are made. These issues may have to be addressed repeatedly throughout the life of a study as treatment and environmental effects may interact over time and space in unpredictable ways. For example, unpredicted growth or mortality of particular species, unintended browsing by elk or deer, or catastrophic environmental conditions may result in unanticipated conditions within experimental sites. These may prompt researchers to consider unplanned manipulations on the treatment units. Without proper planning these manipulations may change the original scope of inference in unintended ways or inadvertently modify an objective.

Suppose that an understory grass, such as *Brachypodium sylvaticum*, invades some, but not all replicate plots of some treatments in an LSME designed to compare one-time thinning practices. Researchers are reluctant to drop the plots from they study and reduce the level of replication, so they consider removing the invaders. However, this manipulation is likely to make more resources available to the overstory trees in the treated plots. A logical choice may be to consider analogous manipulations in the remaining unaffected plots. But if implemented, the plots will no longer represent conditions as originally envisioned. The objective has changed from the evaluation of the single-thinning to thinning-plus-follow-up-removal-of-competition and the scope will be expanded to stands with invasive understory grasses.

SAMPLING WITHIN TREATMENT UNITS

Although treatments are applied to large scales in LSMEs, the experimental unit that receives a large-scale treatment is generally not measured in its entirety; measurements are commonly made on subplots. It is important to note that the role of each subplot is to represent the large-scale plot, analogous to the role of treatment replicates for a treatment. Also, large-scale units are likely to be measured multiple times, perhaps by multiple researchers. During the design phase, coordinating criteria for representative plot layouts and proper measurement standards helps ensure that different responses at the same time and the same responses at different times are comparable.

Often simple random sampling within an experimental unit will represent the replicate adequately. This implies that subplots for measurements are selected from the set of all possible subplots within the experimental unit with a known and equal probability of selection. Occasionally there is a concern that a lack of subplots representing rare conditions within large-scale units will lead to biased response measures and underestimate variation. In these cases, the temptation exists to purposely place subplots in rare or unusual areas to ensure that they are sampled. This method results in biased estimates of plot averages because the rare conditions are over-sampled. An alternative sampling method to account for differing proportions of important conditions, such as stratified random sampling, can be used as long as the proportions of each condition are known. In these cases, it is necessary to calculate weighted averages of the subplot responses to create unbiased estimates for the large-scale unit (Thompson 2002).

CONCLUSIONS

We conclude that coordination and discussion among all participants during the design phase and implementation of LSMEs is a pervasive theme. Explicit lists of objectives, response variables, scales of inference, measurements, timetables for treatment application and measurements should be drafted, frankly discussed, and evaluated. We suggest that developing a hierarchy of objectives that is agreed upon by all participants is crucial for success of LSMEs. This ensures that logistical and conceptual constraints and opportunities are understood. Open and forthright discussions of pros and cons, hypothetical outcomes, and potential pitfalls can go a long way toward foreseeing and producing an optimal study. Future visioning can highlight the importance of particular choices as well as suggest potential solutions for possible setbacks. Thorough and thoughtful planning is paramount.

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Integrating Natural Disturbance Parameters into Conventional Silvicultural Systems: Experience From the Acadian Forest of Northeastern North America

Robert S. Seymour[1]

ABSTRACT

With rare exceptions, the presettlement Acadian forest of northeastern North America was driven by gap dynamics; true stand replacing disturbances were quite uncommon, with recurrence intervals of many thousands of years. After centuries of human exploitation, stand age structures have become simplified, and commercial timber rotations are a fraction (15 to 40 percent) of the lifespan of the common late-successional tree species. Adapting silvicultural systems to strengthen their ecological foundation thus confronts the challenge of converting single- or two-cohort stands to more complex structures via various combinations of regeneration and retention. This paper reviews the region's research and management experience with two fundamentally different approaches to this challenge: regeneration in distinct, relatively small gaps vs. uniform stand-wide regeneration under different levels of overwood reserve trees. A hybrid system is described that combines the proven benefits of shelterwood with the restoration advantages of group selection; in American terminology, the system is an irregular group shelterwood with reserves, similar to the German *Femelschlag* in which gaps are created and gradually expanded over several cutting cycles. Two illustrations of how this (or any) silvicultural system can be benchmarked against natural stand dynamics are provided.

KEYWORDS: Ecological forestry, restoration silviculture, red spruce, shelterwood, selection, conversion, *Femelschlag*.

INTRODUCTION

Foresters in northeastern North America who seek to practice ecologically-based silviculture face many challenges, ranging from incomplete knowledge of ecosystem processes to resisting financial pressures that lead to unsustainable harvesting. This paper attempts to blend our rapidly advancing knowledge of disturbance ecology with existing silvicultural knowledge and experience. My goal is to illustrate how two key attributes of natural disturbances—recurrence interval and patch size—can be readily accommodated by contemporary modifications to a traditional, though little used, silvicultural system.

DISTURBANCE ECOLOGY OF NORTHEASTERN FORESTS

Large-scale commercial forestry in northeastern North America is centered in the northern New England States (Maine, New Hampshire, Vermont) and the Canadian Maritimes (mainly New Brunswick and Nova Scotia). Unlike southern and central New England, much of this region was never settled or cleared for agriculture, and thus remains as a large, virtually unbroken block of contiguous forest stretching from the eastern coast of New Brunswick through the Adirondack Mountains of New York. Two major forest types predominate here, each with many subtypes and local variants in response to edaphic and climatic variation: the so-called "spruce-fir" forest, that contains assemblages of red spruce (*Picea rubens* Sarg.) and balsam fir (*Abies balsamea* (L.) Mill.), and the "northern hardwood forest," dominated historically by sugar maple (*Acer saccharum* Marsh.) American beech (*Fagus grandifolia* Ehrh.), and yellow birch (*Betula alleghaniensis* Britton). Common associates include red maple (*Acer rubrum* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), eastern white pine (*Pinus strobus* L.), and northern white-cedar (*Thuja occidentalis* L.).

[1] Curtis Hutchins Professor of Silviculture, Department of Forest Ecosystem Sciences, University of Maine, Orono, ME 07769-5755, USA.
Email: Seymour@apollo.umenfa.maine.edu

These species can live for 300 years or more, and most are quite shade-tolerant, typically reproducing by advance regeneration that may exist for many decades in the understory before canopy accession (Seymour 1995). Although they can grow and develop well in single-cohort stands and are commonly managed this way today, such structures were uncommon before human exploitation began in the 18th century. Owing to abundant precipitation throughout the growing season, stand-replacing fires were very infrequent, as were stand-replacing windstorms, with estimated return intervals of many centuries to millennia (Lorimer and White 2003). As a consequence, gap dynamics were the most common natural disturbance, which led naturally to a forest structure dominated by late-successional, multi-aged stands (Seymour et al. 2002).

HISTORY OF HUMAN EXPLOITATION AND MANAGEMENT

Centuries of human exploitation for forest products, first for large sawlogs and later (ca. 1900) for smaller-diameter pulpwood, have radically changed the forest structure. Remnants of the primary, old-growth forest are quite rare, and many, such as the Big Reed Reserve in northern Maine owned by The Nature Conservancy, have been reserved from commercial logging and studied intensively by ecologists (e.g., Fraver 2004). The typical commercial forest landscape is dominated by stands that are younger and more even-aged than during presettlement. Changes in species composition have been less dramatic; nevertheless, typical stand compositions have shifted from the slower-growing, late-successional species to those that are favored by frequent harvest disturbance, such as red maple, paper birch (*Betula papyrifera* Marsh.), aspen (*Populus* spp.), and balsam fir. It is not uncommon to find legacies of the presettlement forest remaining in many stands, such as large cull trees and small, long-suppressed saplings of late-successional species absent from the overstory, but these are usually a byproduct of their low commercial value, not a conscious act of retention.

When I arrived in Maine in the late 1970s, the landscape was dominated by well stocked, even-aged spruce-fir stands that, I was told, had originated after the devastating spruce budworm (*Choristoneura fumiferana* Clem.) outbreak ca. 1913-19. Careful reconstructions of these stands using records and increment cores, coupled with review of early descriptions of the original forest and early harvesting (e.g., Cary 1894, Hosmer 1902) invariably revealed that these even-aged stands had originated by some heavy, often repeated, timber harvests ca. 1880-1925. Only pure fir stands (which were originally neither common nor extensive) seemed to have a unique budworm origin (Seymour 1992). Many of these dense, even-aged, and ecologically immature spruce-fir stands were again clearcut during the 1980s, partly in response to the budworm outbreak of that time. Many industrial landowners treated large areas of the regenerating third-growth forest with herbicide release and precommercial thinning, with little attempt to favor red spruce over fir. Now, as these stands approach commercial size, there are large areas of 25-year-old, spaced, nearly pure fir stands, where 150 years before stood old-growth red spruce-yellow birch forests with fir as a minor component.

SILVICULTURE FOR ECOLOGICAL RESTORATION

Challenges

Any serious attempt at ecological forestry (see Seymour and Hunter 1999) in this region must confront the simplified age structures and altered compositions of repeatedly harvested stands using a patient restoration approach. The goal of such a restoration strategy is to re-create a forest dominated by diverse multi-aged stands, with at least some having a late-successional component that is deficient in the commercial forest. In the Acadian region, this problem is arguably more difficult than in regions like the Pacific Northwest where the natural stand-development patterns follow a single-cohort model, and the challenge is merely softening clearcuts with structural retention measures. In the Northeast, leaving scattered islands or reserve trees in clearcuts or uniform shelterwoods of >10 ha, although valuable in some respects, often fails to address the more fundamental mismatch of even-aged silviculture with natural processes.

During the past decade or so as ecological forestry concepts have entered mainstream thinking, I believe that most academics and scientists share a common view about the difference of our present forest from that of presettlement. Practitioners are generally more skeptical, not necessary of the underlying science, but of its relevance to their day-to-day existence. Further, just as the consciousness of ecological forestry is being raised, there has been a wholesale sell-off of large parcels formerly held by forest industry to timberland investors whose time horizons are much shorter and who expect double-digit returns. Relative to the goals of restoration and ecological sustainability, much of this former industrial forest just needs a “rest,” yet it is faced with ever-increasing pressure to generate income from the remaining growing stock. My own experience suggests that stewards of public forests, especially those under management by state forestry agencies in the United States, have resisted such pressures and tend to be more receptive to restoration silviculture than many privately owned forests.

Possible Restoration Pathways

Conceptually, the challenge of converting even-aged stand structures to more complex ones is straightforward: a series of regular harvest entries, spaced out over a relatively long conversion period (e.g., 50 to 100 years), each regenerating only a relatively small portion of the stand. Of course, this is easier said than done, especially if the stand is already understocked from prior harvests. Nyland (2003) discusses two different ways to approach this problem: uniformly distributed reductions in overstory density at each cutting versus creation of distinct canopy gaps. As diagrammed by Nyland, the first option begins as a light, uniform shelterwood establishment cutting and ends (after 5 cutting cycles) as single-tree selection. The second option can be categorized as patch or group selection throughout. Both assume equal cutting cycles and an age-balanced stand at the end of the conversion period.

The shelterwood method is commonly recommended in this region for regenerating spruce-fir, northern hardwood, and white pine-red oak forests (Hannah 1988, Seymour 1995) and is viewed by many foresters as the best way to restore degraded stands to higher timber productivity. Although sometimes considered an alternative to even-aged management because it involves "partial cutting" at the establishment stage, shelterwood management is at best a two-aged system depending on the density of reserve trees, if any. As practiced by most private owners, establishment cuttings are uniformly applied and fairly heavy (40- to 60-percent removals); furthermore, reserve trees left after overstory removal are not numerous (generally <10 percent of the original stocking) and thus do not significantly affect the dominant younger cohort. So, although uniform shelterwoods may be an effective method to improve species composition and provide economic returns, they fail as a system for restoring multi-aged stand structures.

Group selection cutting is much less common than shelterwood, but is gaining popularity in formerly high-graded northern hardwood forests with an overabundance of beech regeneration. The improved light environment of even small gaps gives sugar maple and the birches an advantage over the vegetative beech reproduction, as long as advance regeneration of maple is established and birch seed reaches the disturbed gaps (Seymour 1995). Group selection is quite uncommon in spruce-fir forests; examples are limited to some public ownerships and small private woodlots. Although preferable to shelterwood for ecological restoration, group selection cutting has several drawbacks. If the matrix between groups is not treated, the overall harvest can be very light and thus problematic economically. Not treating the matrix, however, risks losing volumes of valuable but short-lived species, such as balsam fir, paper birch, and aspen, that might not survive until the next entry.

Principles and Specifics

To convert uniform stands to more irregular, multi-aged structures, one must consciously regenerate a portion of the stand at each entry while keeping the canopy of the surrounding matrix relatively intact and thus, unregenerated. A comprehensive review of natural disturbance rates in this region (Seymour et al. 2002, fig. 1) suggests that the area regenerated should average about 1 percent per year, equivalent to a 100-year return interval. Assuming the goal is a balanced within-stand age structure at the end of the conversion period, one simply multiplies the annual disturbance rate by the cutting cycle, just as one would do in a forest of even-aged stands under area regulation (Nyland 1996). Adopting a cutting cycle of 20 years thus would dictate that each entry regenerate 20 x 1% = 20% of the stand at each entry. Furthermore, regeneration should occur in small gaps (under 0.1 ha) in order to remain within the bounds of natural disturbance parameters (Seymour et al. 2002). Finally, to restore late-successional characteristics, reserve trees must be retained in the gaps as they are regenerated; otherwise, there will obviously be no trees over age 100 when the conversion is complete. Ideally, reserve trees are retained permanently and should consist primarily of long-lived species from the main canopy. As they grow to ecological maturity and eventually die, they will restore an important late-successional structural component that is typically absent from managed forests; they will function as biological legacies (Franklin et al. 1997, Seymour and Hunter 1999) and replenish the pool of large, woody material on the forest floor.

I believe that the guiding principle of such a silvicultural system should be a stand structure based on area, not tree size. Such a guide takes the form of a within-stand age structure, rather than a tree size structure such as the negative exponential diameter distribution commonly associated with balanced single-tree selection cutting (O'Hara 1996, Seymour and Kenefic 1998, Smith et al. 1997). Specifically, an area-based structure defines what percentage of the stand is regenerated at each entry, along with a distribution of patch (gap) sizes that comprises this area. An area structure requires the forester to consider the regeneration process explicitly at each entry, and thus avoids the historical pitfalls of size-based, multi-aged systems that did not lead to adequate ingrowth of the desired species and were thus abandoned throughout North America during the 1950s in favor

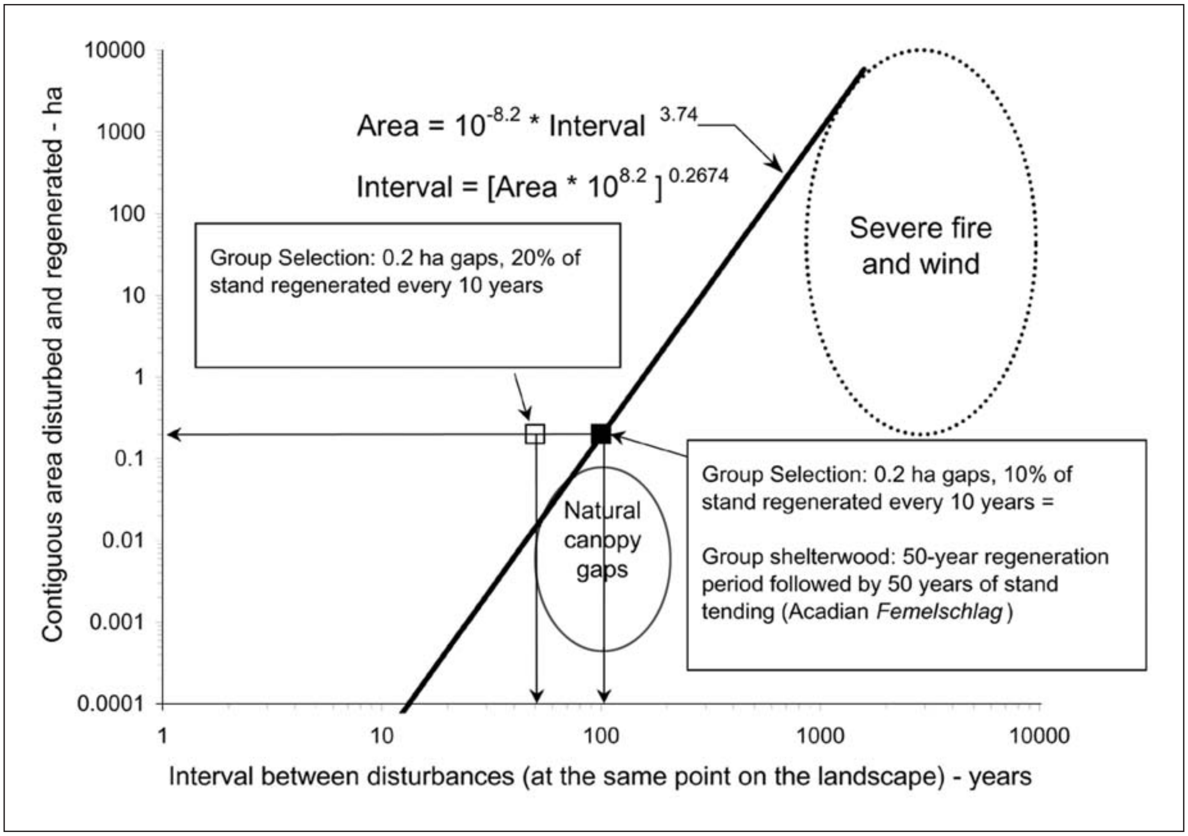

Figure 1—Evaluating the natural disturbance comparability of two gap-oriented silvicultural systems, using the reference metric from Seymour et al. (2002).

of single-cohort systems (Curtis 1998; Seymour, in press; Smith 1962).

Uniform vs. Gap-oriented Spatial Patterns

Relative to the goal of restoring age diversity, I believe that Nyland's (2003) first option, repeated uniform cuttings, is not practical in our region and, arguably, does not work ecologically. First, Acadian forests tend to develop dense understories of advance regeneration under even light canopy disturbances; hence the appeal of the simple uniform shelterwood method for production systems based on natural regeneration. After a uniform cutting to 60-percent relative density as recommended by Nyland (2003), the understory will invariably fill up with tolerant advance growth. Further, light uniform removals from the overstory serve only to release this regeneration, not establish new cohorts as required. In effect, the understory quickly reaches a stem-exclusion condition (Oliver and Larson 1996), and the stand never contains more than two cohorts. At best, a third cohort might establish after the final overstory removal in areas disturbed by harvesting equipment, but this is a common feature of all systems. For conversion systems to work over time, the dominant matrix must be kept at sufficient density to prevent regeneration over most of the stand at a given time; regeneration should occur only in defined gaps created at each entry.

Another important drawback of uniform patterns is the fact that the light cuttings required for true restoration, typically no more than 10- to 20-percent removals, are quite impractical operationally if distributed evenly throughout the stand. Concentrating such light entries, as done in gap-oriented systems, promotes harvesting efficiency and costs should be little more than for clearcutting if haul roads are in place. Gap systems also allow other silvicultural treatments (e.g., enrichment planting to restore species, early stand tending) to be conducted efficiently.

A Hybrid Silvicultural System:
The Acadian *Femelschlag*

In 1994, a team of forest scientists and wildlife ecologists from the University of Maine faculty set out to design a long-term experiment in ecological forestry known as the Forest Ecosystem Research Program (FERP). This program would complement the existing, conventional silvicultural systems on the Penobscot Experimental Forest maintained by the USDA Forest Service Northeastern Research Station since 1950 (Sendak et al. 2003). We based our silvicultural systems on the disturbance rates, patterns, and structural features of natural forests as best we understood them. One system chosen was a traditional light group-selection cutting that removed 10 percent of the stand in small gaps on a 10-year cutting cycle while retaining 30 percent of the initial growing stock within the gaps as permanent reserve trees. Although such a system arguably mimics natural dynamics closely, the overall harvest rate is so light that is was difficult to carry out logistically and economically.

In an attempt to formulate a more operationally feasible system without sacrificing its ecological basis, we devised a hybrid between group selection and uniform shelterwood. The key concept is to apply the well-known principles of shelterwood regeneration in a patch-wise fashion within the stand, rather than uniformly throughout, leaving reserve trees in the groups after they are fully regenerated. Instead of stand age structure changing *temporarily* as in a uniform shelterwood, group shelterwood systems vary *spatially*, and at times contain all stages of the shelterwood sequence: unregenerated matrix awaiting treatment, two-storied patches following establishment cutting, and free-to-grow sapling regeneration after removal of the overstory except scattered reserves. In order to make harvesting as efficient as possible and to retain some intolerant species in the regeneration, we chose a gap size of 0.2 ha, slightly larger than most natural gaps (Seymour et al. 2002). Further, we designated about 10 percent of the initial growing stock as permanent reserve trees, making this a "group shelterwood with reserves." We chose to carry out the conversion cuttings in five entries spaced 10 years apart, and then allow the stand to develop without regeneration cutting for another 50 years. This equals a 1-percent annual disturbance rate over the entire 100-year conversion period, but is effectively "front-loaded" during the first 50 years at 2 percent per year. Unlike a classical group selection system with a constant cutting cycle, this system explicitly does not attempt to achieve any sort of balanced within-stand age structure, just a diverse, irregular one that nevertheless represents quite a departure from the initial single-cohort structure.

The most accurate description of this system using contemporary North American silvicultural terminology would be an "irregular group shelterwood with reserves." *Group* comes from the spatial pattern of the cuttings and is needed to distinguish it from a uniform application. *Irregular* comes from the extended regeneration period relative to a more conventional shelterwood, and describes the uneven height structure of the resulting regeneration. *With reserves* comes from the retention of trees from the original cohort beyond the regeneration period, for reasons unrelated to the regeneration process itself. European foresters have long applied such a system, known in Germany as the *Femelschlag*, in which the groups under regeneration are expanded at each entry until they coalesce (Spurr 1956). In his classic description of European silvicultural systems, Troup (1928) describes several regional variants of the *Femelschlag* widely practiced at that time for converting even-aged stands to more irregular structures. We have also adopted this approach in our FERP experiments, and have thus chosen to describe our system as the Acadian *Femelschlag*.

Some Application Details: Locating Skid Trails, Initial Gaps, and Reserve Trees

We elected to harvest within the matrix between groups during the first entry, mainly to presalvage balsam fir, paper birch, and aspen that were reaching their natural life span. In the matrix, we were very careful not to remove any large dominant trees that would make permanent canopy gaps and thus create unwanted nuclei of regeneration. Skid trails were designated to connect the gaps, and occasional spur trails were needed to treat the intervening matrix. In future entries when gaps are expanded, trails will be relocated through the matrix where necessary to avoid damaging established reproduction.

Initial gaps were located in two different stand conditions. In patches of well-established advance regeneration resulting from partial canopy breakup in the two decades prior to initiating the experiment, the overstory was removed completely except for the requisite reserve trees. Areas of these existing gaps were estimated in the field and sketched on a stand map. Additional gaps were located as needed throughout the more intact matrix until the requisite area (20 percent of the total stand) was achieved. In this latter case, the cut within the gap attempted to leave a shelterwood overstory basal area of 14-18 m^2/ha (60 to 80 ft^2/acre) to provide shade and seed for new recruitment. These overwoods will be removed in the second entry (except permanent reserve trees) as the gaps are expanded.

Reserve trees were designated at the same time the stand was marked for cutting. Any tree with obvious wildlife usage (e.g., large cavities) was designated; others were selected from the larger d.b.h. classes of long-lived, and sometimes uncommon, species. Since our goal was to permanently retain 10 percent of the stand, and the target residual basal area, including gaps, was about 23 m^2/ha (100 ft^2/acre), we used a 10 basal area factor (English) wedge prism to distribute reserve trees such that no place in the stand was lacking at least one "in" tree.

Quantifying What Is "Natural" as a Silvicultural Benchmark

Silviculturists in the Northeast seeking to emulate natural disturbance regimes have historically relied on general ecological principles and intuition. To overcome this obstacle, we created a simple metric based on a comprehensive review of disturbance literature for the region that allows foresters to assess how closely their silvicultural systems approach natural patterns (fig. 1). The axes of the diagram—intervals between disturbance and contiguous areas disturbed—both have direct silvicultural analogues (Seymour and Hunter 1999). For systems that do not regenerate the entire stand in one entry (e.g., group selection), the frequency should be thought of as the time required to regenerate the entire stand, assuming patches do not overlap. This is given by the formula: frequency (or effective rotation) = (cutting cycle, in years)/(proportion of stand regenerated at each entry). The fitted line that bounds the upper limit of the disturbance data becomes the space-time benchmark point for any system.

Consider a group-selection system that regenerates 20 percent of the stand at each entry, in patches averaging 0.2 ha, on a 10-year cycle. The return interval (effective rotation) is thus 10/20% = 50 years. Next, compute the natural return interval of a 0.2-ha patch: Interval = $[0.2 \times 10^{8.2}]$ 0.2764 = 101 years (from fig. 1). The ratio of the planned return interval to its natural analogue is termed the natural disturbance comparability index, in this case 50/100 = 0.5, meaning that such a system would effectively regenerate this stand in gaps of this size about twice as rapidly as natural disturbances would. Note that lengthening the cutting cycle to 20 years, or reducing the patch size to 0.014 ha, would place the system exactly on the line. The Acadian *Femelschlag* described above also falls exactly on the line because the entire "rotation" (the time between the beginning of gap creation in two successive applications of the system to the same area) is effectively 100 years (50 years of group regeneration cutting followed by 50 years of stem exclusion stand development during which only intermediate treatments are applied).

It is also instructive to compare the planned age distribution of the irregular group shelterwood with that of undisturbed old-growth stands in the region. The age structure of the shelterwood will be, by design, distinctly bimodal: five closely spaced cohorts that span a range of about 40 to 50 years resulting from the expanding gap cuttings, plus a population of much older reserve trees chosen from the initial stand. For example, if the stand were 90 years old at the beginning (as in the case of one of the FERP experimental blocks), by the time the regeneration process is complete, these reserves will be 140+ years old, and nearly 200 after one complete cycle when the stand is again ready for regeneration cuttings.

Figure 2 shows the age structure of three old-growth red spruce stands in the Big Reed Reserve in northern Maine as reconstructed by Fraver (2004). Note that all are somewhat bimodal, two distinctly so, indicating that recruitment in such stands is episodic and irregular. Note that irregular group shelterwood systems with reserves—with extended periods of stand regeneration in patches, followed by periods of stem exclusion—arguably emulate this structure more faithfully than the classic balanced single-tree or group selection stand with continuous, temporally constant recruitment. In the group shelterwood, the managed cohorts would be analogous to those under age 100 in the natural forest, and the reserve trees would be analogous to the old-growth trees over the managed rotation (ca. 100 years). In practice, a managed stand would have more growing space allocated to cohorts under age 100 and less to the old-growth legacy, assuming legacy trees would never be harvested.

CONCLUSIONS

Irregular group shelterwoods with permanently retained reserve trees offer great promise as a viable method to restore age diversity and "naturalness" to Acadian forests that have become simplified from over a century of heavy cutting. Like any silvicultural system, however, they are not a panacea for all conditions, even where landowners are committed to ecological restoration. In pure, single-cohort stands dominated by early successional species, restoration of later-successional species which may invade the understory is the main ecological objective, and uniform shelterwoods (with reserves) may offer the only way to capture the value in the present stand before it reaches maturity. In this case, restoration of age structure can then begin during the next rotation, where the presence of more long-lived species offers more options. Conversely, in stands that have been managed to retain multi-aged, late-successional qualities, some form of selection cutting with more regular entries and smaller gaps may be more appropriate.

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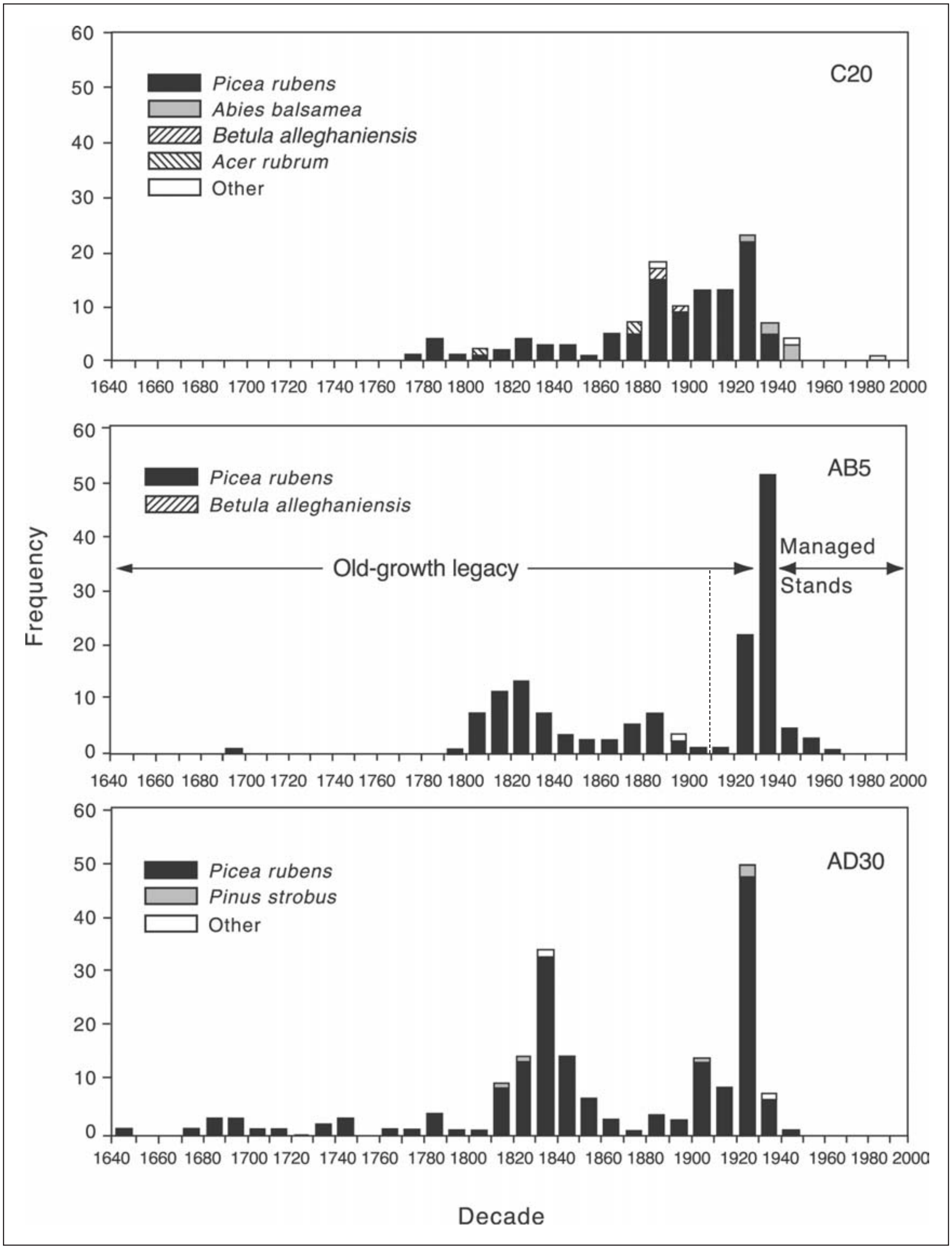

Figure 2—Age-structures of three old-growth red spruce stands in the Big Reed Reserve, T. 8 R. 10, Maine (Fraver 2004), showing the very irregular patterns of canopy recruitment over three centuries. Group shelterwood silvicultural systems can mimic this pattern, assuming the 1-100 cohorts represent the managed (harvested) stand, and those over 100 are reserve trees that provide the biological legacy. In practice, a managed stand would have more trees in the "managed" component and fewer in the old-growth legacy.

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Do Innovative Experiments Lead to Innovative Silvicultural Systems?

Klaus J. Puettmann[1]

ABSTRACT

Innovative experiments provide a unique opportunity to facilitate development of new, innovative silvicultural systems. Experiments with clear objectives and expectations can be set up to provide information about a set of silvicultural treatments, thus testing silvicultural systems directly. Innovative experiments are especially useful for investigation of large-scale treatments and responses and provide opportunities for investigation of small-scale responses under a wide range of treatments. To fully utilize these experiments requires coordination of studies and "innovative" integration of results.

KEYWORDS: Silvicultural systems, large scale assessment, small scale ecosystem responses, integration.

INTRODUCTION

The controversy over forest management in the Pacific Northwest (PNW) of the United States in the late 1980 and early 1990s questioned the ability of traditional silvicultural systems to satisfy the range of landowner objectives, especially on public land. This uncertainty resulted in an effort to establish several large-scale management experiments or LSMEs (see Monserud 2002). The experimental approach of LSMEs is quite innovative: these studies include multiple objectives covering a variety of scales and disciplines and thus facilitate integration of a suite of ecosystem responses. In addition, treatments are applied to large experimental units and results can be directly transferred to standard management operations. Although all LSMEs have commonalities, the range of study approaches reflects the variety of forest conditions and management objectives across the region and ownerships. Table 1 provides an overview of initial objectives and treatments for several innovative studies. Experiments that deal with final harvest situations (the first four studies) linked their objectives closer to silvicultural systems than studies that dealt with intermediate stand treatments (the last three studies). This is likely due to the dominance of final harvests in defining silvicultural systems. Some experiments were set up to directly test silvicultural systems, e.g., the Montane Alternative Silvicultural Systems study or Capitol Forest study. A second set of studies have a more limited scope and document whether a specific silvicultural practice, such as thinning or variable retention, hasten development of late successional attributes, e.g., the Young Stand Thinning and Diversity study or Demonstration of Ecosystem Management Options study.

Silvicultural systems outline future conditions, values, and practices necessary to reach desired objectives, and all of these aspects are important when evaluating innovative experiments. Silvicultural systems are typically defined by the regeneration system, competition control, fertilization regimes, intermediate manipulations of stand density and composition, and, primarily, by the method of harvest, i.e., they deal with all stages of stand development and integrate information from various disciplines. Consequently, most ecological and silvicultural research projects can provide useful information. However, studies that are defined by a coordinated set of treatments or manipulations are more relevant to assessment and development of silvicultural systems. Table 1 lists the proposed treatments as stated in initial study plans of innovative experiments. A clear understanding of desired future conditions seems to be indicative of more detailed description of future treatments. Studies

[1] Associate Professor , Oregon State University, Department of Forest Science, 321 Richardson Hall, Corvallis, OR 97331-5752.
Email: klaus.puettmann@oregonstate.edu

Table 1—Objectives and treatments of selected large-scale management experiments, as listed in their initial study plans

Study	Objective	Treatment type	Additional treatments	Source
Capitol Forest	Compare different silviculture regimes	Clearcut, retention, patch cut, group selection, thinning[a]	(If needed) over and understory manipulations	Curtis et al. 2004
Alternatives to clearcutting	Determine how even-and uneven-age silvicultural systems affect stand features and process	Clearcutting, patch retention, single tree selection, group selection. (uniform and patchy)[b]		McClellan et al. 2000
Montane Alternative Silvicultural Systems	Test alternative silviculture systems	Patch cut, green tree retention, shelterwood cut, clearcut		Beese and Bryant 1999
Date Creek	Examine ecosystem processes in uncut, partially cut, and clearcut stands	2 levels of partial cutting, clearcut		Coates et al. 1997
Demonstration of Ecosystem Management Options	Study ecological and social effect of variable retention harvest	4 retention levels, dispersed and aggregated		Aubry et al. 2004
Forest Ecosystem Study	Test whether late-seral forest attributes can be developed (hastened) through silviculture	Variable density thinning (repeated), underplanting	2nd thinning entry, underplanting	Carey et al. 1999
Young Stand Thinning and Diversity Study	Test whether different thinning, underplanting, and snag creation treatments can accelerate the development of late-successional habitat	2 thinning intensities, gap creation,		http://www.fsl.orst.edu/ccem/youngstd/home.htm
Density Management Study	Determine if density management treatments result in differences in stand structure and habitat diversity	3 thinning intensities (homogenous and variable), gap creation, leave island	Overstory treatments, precommerical thinning	Thompson and Larsen 2003

[a] May imply multiple overstory manipulations in accordance with silvicultural system.

[b] Usually includes an uncut control treatment.

with investigation of silvicultural systems as the main objective generally define the set of overstory treatments in accordance with the systems that are investigated. Information in these study plans includes tentative schedules for follow-up cuttings, such as removal cuts in shelterwoods or subsequent entries in group selections. With notable exceptions, the study plans provided less information about snag and downed wood management and treatment of soil, regeneration, and understory vegetation. Although future treatments may have to be flexible to accommodate unexpected trends and developments, a clear hierarchy of objectives (see Ganio and Puettmann 2005) will facilitate definition of future treatments. For example, a clear definition of desired stand structure determines the role of understory hardwoods and multiple layers of a conifer canopy and is necessary for defining future treatments of understory vegetation and conifer regeneration. If the development of multiple conifer overstory canopy layers has priority, vegetation management to provide good growing conditions for conifer regeneration is desirable or necessary. On the other hand, if the desired future stand structure includes diverse understory vegetation with a shrub and hardwood layer, these components should not be removed, even though they may impact growth of regenerating conifers.

The study plans also highlight the importance in distinguishing between the two approaches. The first compares effects of implementing different silvicultural systems, whereas the second provides opportunities to improve our understanding of processes important for developing and implementing silvicultural systems. These approaches are not mutually exclusive, but the distinction is reflected in the definition of study objectives and treatments and has to be kept in mind throughout the discussion below.

LARGE-SCALE AND LONG-TERM ASSESSMENTS OF TREATMENTS

A defining factor, treatment unit size has a great impact on scientific contributions of innovative experiments. Treatment unit size is experimentally driven by the context of processes and structures studied in the experiment, i.e., by the phenomena of interest with the largest extent (see Wiens 1989). For many studies in the PNW, the size was defined by songbirds. To ensure multiple home ranges of songbirds within treatment units (Hagar 2001), treatments in the PNW were commonly applied to 40- to 50-acre units, similar to typical stand sizes in the region. The large experimental units ensure that results from application and assessment of treatments are directly applicable to stand-level management practices. Consequently, innovative experiments provide unique opportunities to develop information about issues for which information from smaller experiments cannot be scaled up because the assumption of scale-independent uniformity is not met. Another example of questions that require stand-level studies focuses on operational aspects of silvicultural systems. Innovative experiments have provided information about cost of layout and hauling for newly developed silvicultural treatments, such as creation of small gaps as part of a thinning operation (Kellogg et al. 1998). Other harvesting aspects, such as the amount of damage to residual trees or distribution and impacts of slash, also require stand-level assessments. A third set of issues that benefit from innovative experiments includes public perceptions of silvicultural systems.

Due to their size, treatments in innovative experiments are commonly implemented as part of “normal” management operations. This provides opportunities for technology transfer and will facilitate future adaptations of innovative silvicultural systems. On the other hand, operational implementations can limit the choice of treatments because of logistical considerations or reluctance of managers to implement treatments that go beyond commonly accepted standards.

The inherent long-term nature of innovative experiments will provide information on issues that do not lend themselves to temporal scaling. Although models exist that predict tree development in typical stand conditions quite well, the prediction of other responses may be more complicated and require longer time scales for investigations. For example, predicting regeneration of tree or other plant species or size and trends of wildlife populations includes stochastic elements that are not easily quantified in short, small-scale experiments. The size and long-term nature of innovative experiments may allow investigation of stochastic patterns and the variability of responses. Similarly, natural disturbances are usually stochastic, and their interaction with natural ecosystem development and management practices is sometimes ignored in management planning. Innovative experiments may provide an opportunity to document their frequency, patterns and impacts under different treatment regimes.

SMALL-SCALE ASSESSMENT OF ECOSYSTEM PROCESSES

A second advantage of innovative experiments is that they provide opportunities for small-scale and short-term studies. Many processes, such as seedling responses to overstory cover, act on scales smaller than the stand level. In homogenous treatment units, these aspects can be studied at larger scales to provide a better understanding of the variation of responses. A large number of subsamples can provide an estimate of variation around the mean, thus allowing researchers to quantify the distribution of responses. A second option to investigate small scale processes is to ignore scale discrepancies and study them by using a smaller grain (see Wiens 1989). For example, to study seedling responses to overstory cover, large, evenly-spaced thinned treatment units may be supplemented with small underplanted plots. In this context, large-scale treatments that are highly variable provide better opportunities to gain more information about small-scale ecosystem processes. One common example is when stand-level treatments are a combination of subtreatments, such as gaps placed randomly in an evenly spaced matrix (e.g., in the Young Stand Thinning and Diversity study). Under this setup, comparisons of (small scale) conditions in gaps and matrix may provide useful information. Alternatively, innovative studies provide opportunities to investigate aspects relating to the whole set of treatments that are part of silvicultural systems, such as the performance of different species, the impact of fertilization, or weed control under a range of overstory conditions (created by the stand-level treatments).

Further opportunities to take advantage of the range of conditions created by large-scale treatments in innovative experiments include more detailed analyses of within-treatment variation. Highly variable treatments, such as variable density thinning, may result in a wide gradient of conditions. In many cases, a clear distinction (e.g., where a gap stops and a matrix begins) is not always possible or even desirable. Instead, conditions change gradually, thus resulting in large experimental gradients over a small spatial scale. Common gradients include the transition from closed canopy stands to clearcuts or gradients from gaps or leave islands into thinned stands. Using a common independent variable, such as overstory cover, allows investigations of gradients under the range of conditions found in innovative experiments. Examples include gradients starting in matrices with different densities or gradients ending in gaps or leave islands of different sizes. This provides opportunities to gain detailed information about the scale of variability and underlying mechanisms. It also helps in understanding the average treatment response. In addition, this information provides foresters with an opportunity to quantify tradeoffs when choosing the range and spatial layout of treatments in new silvicultural systems. Better ecological understanding may also be helpful when implementing innovative silvicultural system in stands that are outside the scope of the studies.

INTEGRATION OF STUDIES

A third unique feature of innovative experiments is the multitude of objectives and investigators. Most experiments provide information on a range of ecosystem responses, including overstory trees, understory vegetation, mycorrhizal associations, and animal habitat and populations. Multidisciplinary assessments of silvicultural systems are of special interest on ownerships with a complex set of management objectives or constraints. Integrating results from various disciplines into complex descriptions of ecosystem responses is very difficult and has been slow to develop. This is at least partially due to the lack of a coordinated study effort. Information about different ecosystem responses is commonly derived from an array of experiments with different initial conditions, treatments, assumptions, etc. Researchers involved in innovative experiments have the opportunity to plan for integration up front. Not only do innovative experiments have the benefits of common experimental designs and treatments, they also provide the opportunity to implement an experimental layout that is specifically designed to facilitate integration of information from various disciplines (see Ganio and Puettmann 2005). To accomplish this requires standardizing procedures and coordinating timing and location of data collection and analysis.

Using information gained from innovative experiments to develop new, creative silvicultural systems requires additional steps. I suggest that innovative analytical methods be developed and used to fully take advantage of innovative experiments. The use of analytical or predictive modeling approaches that integrate information from short-term and small-scale investigations may be especially beneficial. These models have to accommodate spatial and temporal variability so we can understand silvicultural systems that include complex stand structures. Models with small spatial resolution are better able to account for variation inherent to site or vegetation conditions. As highlighted above, innovative experiments can provide information about stochasticity and variability of responses, and this should be included into the models. For example, treatment responses could be determined stochastically, i.e., data from innovative experiments would provide the probability of tree regeneration. A random number generator would then be used to decide the fate of each gap. Alternatively, or additionally, the simulation models could predict the distributions rather than average response. These models may have limitations in predictive accuracy for any single location within a stand. However, they can use a variety of information sources, take advantage of the unique features of innovative experiments, and thus can be a very powerful tool in developing hypotheses and predicting ecosystem response to new, creative silvicultural systems (for examples, see Coates et al. 2003).

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Variable-Retention Adaptive Management Experiments: Testing New Approaches for Managing British Columbia's Coastal Forests

William J. Beese,[1] B. Glen Dunsworth,[2] and Nick J. Smith[3]

ABSTRACT

In response to changing public values and scientific knowledge, the variable-retention (VR) approach to forest harvesting has become widespread on forest lands in coastal British Columbia (BC). Variable retention is both a tool for achieving stand-level objectives, such as retention of trees to enhance structural diversity, and an important strategy for achieving forest-level goals, such as conservation of biodiversity. The VR approach can be applied using the new retention silvicultural system, officially adopted in BC, or by adapting traditional systems with long-term reserves.

Weyerhaeuser's BC Coastal Timberlands is implementing an innovative forest management strategy that includes the use of landscape zoning, variable retention and adaptive management to balance ecological, social and economic objectives. The program includes monitoring of both operational cutblocks and operational-scale experiments. A set of long-term, variable-retention adaptive management (VRAM) experiments were designed by a team of scientists and foresters to address many of the questions regarding the layout and objectives for VR cutblocks. Fifteen VRAM blocks are being installed by our BC coastal operations over a 7-year period. There are three replicates of five comparisons: group retention level, group size, dispersed retention level, riparian retention level, and short- or long-cycle group selection. Each VRAM block consists of five 20 ha treatments: three VR options, clearcut, and uncut. To date, four VRAM sites have been logged and four are scheduled for completion in 2004. Monitoring includes a focused set of attributes and organisms. An adaptive management framework was designed so that results will feed back to management.

KEYWORDS: Adaptive management, biodiversity, British Columbia, variable retention.

INTRODUCTION

In recent years, changing public values and scientific knowledge have led forest practices toward achieving broader objectives on public forest lands in British Columbia (BC). Global concerns about biological diversity have raised demand in the marketplace for wood from forests under sustainable forest management certification. In 1998, MacMillan Bloedel (now Weyerhaeuser, BC Coastal Group) announced "The Forest Project"—an innovative forest management strategy designed to achieve a balance of ecological, social and economic goals for managing over 1.1 million hectares (ha) of mainly public forest land in coastal BC. The strategy includes landscape zoning, increasing old-growth conservation, adopting variable retention harvesting, implementing a monitoring and adaptive management program, and achieving independent forest certification. This program, now known as Weyerhaeuser's BC "Coast Forest Strategy," is described by the authors in previous articles (Beese 1998, Beese et al. 2001, Dunsworth and Beese 2000) and on a website (www.forestry.ubc.ca/conservation/forest_strategy).

[1] Forest Ecologist, Weyerhaeuser, BC Coastal Timberlands, 65 Front Street, Nanaimo, BC, V9R 5H9, Canada. Email for corresponding author: Bill.Beese@weyerhaeuser.com

[2] Glen Dunsworth Ecological Consulting, 7857 Shangri-la Road, Lantzville, BC V0R 2H0, Canada

[3] Manager, Growth and Yield, Weyerhaeuser, BC Coastal Timberlands, 65 Front Street, Nanaimo, BC, V9R 5H9, Canada

Use of the variable retention (VR) approach to harvesting is a recent development in BC; the term was first introduced by the Clayoquot Scientific Panel (1995) and subsequently described in a broader context by Franklin et al. (1997). Prior to this, there was very little experience in using partial cutting silvicultural systems in the old-growth forests of the BC coast (Arnott and Beese 1997). In 1999, the BC government officially recognized the "retention silvicultural system" in its forestry regulations. Weyerhaeuser phased-in VR throughout BC coastal operations over a 5-year period, completing over 90 percent of our harvesting using VR in 2003.

One of the goals of the Coast Forest Strategy is to sustain biodiversity, or biological richness and its associated values, within Weyerhaeuser's BC coastal tenure. We use three indicators of success to focus our goals and monitoring (Kremsater et al. 2003):

1. Ecologically distinct ecosystem types are represented in the nonharvestable landbase to maintain lesser known species and ecological functions.
2. The amount, distribution, and heterogeneity of stand and forest structures important to sustain biological richness are maintained over time.
3. Productive populations of forest-dwelling species are well distributed.

Because the effectiveness of variable retention and broad landscape zoning in maintaining biodiversity is largely untested, adaptive management is a key component of the Coast Forest Strategy. Adaptive management is "a dynamic approach to forest management in which the effects of treatments and decisions are continually monitored and used, along with research results, to modify management on a continuing basis to ensure that objectives are being met" (Helms 1998). We need to examine the impacts of our practices on both biodiversity and our ability to manage forests for commercial production; therefore, linking monitoring back to management action is a fundamental component. The program will evaluate biological indicators by monitoring both operational treatments (i.e., normal business practices) and designed experimental treatments. The focus of this paper is to describe the adaptive management experiments that are being implemented as part of the Coast Forest Strategy.

OBJECTIVES

Variable-retention adaptive management (VRAM) experiments were designed by a team of scientists and foresters to address many of the questions regarding the layout and objectives for VR cutblocks. The objectives of these experiments are to

1. Establish a series of designed comparisons of variable retention options to support an adaptive management approach;
2. Compare a range of retention levels and spatial patterns of retention in several forest types;
3. Monitor the short-term and long-term impacts of variable retention options on forest growth, structural attributes and selected forest-dwelling plant and animal species.

VRAM sites focus on the stand-level questions associated with biodiversity indicators 2 and 3 above (forest structure and species) as well as the silvicultural implications of VR options. Key questions include: What is the effect of the amount (percentage of retention level) and pattern of retention (dispersed trees, small groups, large groups)? What is the effect of size of opening and timing of adjacent openings? What is the effect of group location on small stream-riparian impacts?

METHODS

Experimental Design

The experimental design for the VRAM areas consists of three replicates for each of five comparisons:

1. **Group retention levels:** 10-percent, 20-percent, and 30-percent group retention; groups range in size from 0.2 to 0.5 ha.
2. **Dispersed retention levels:** 5-percent, 10-percent, and 30-percent dispersed retention; single trees to small groups up to 0.1 ha.
3. **Group size:** large groups (0.8 to 1.2 ha), small groups (0.2 – 0.5 ha), and dispersed trees (single trees to very small groups up to 0.1 ha); the retention level is 15 percent for all treatments.
4. **Group removal – short/long cycle:** group removal – short cutting cycle (5 to 7 years), group removal – long cutting cycle (20 to 30 years); groups in both treatments range in size from 0.1 to 1.0 ha.

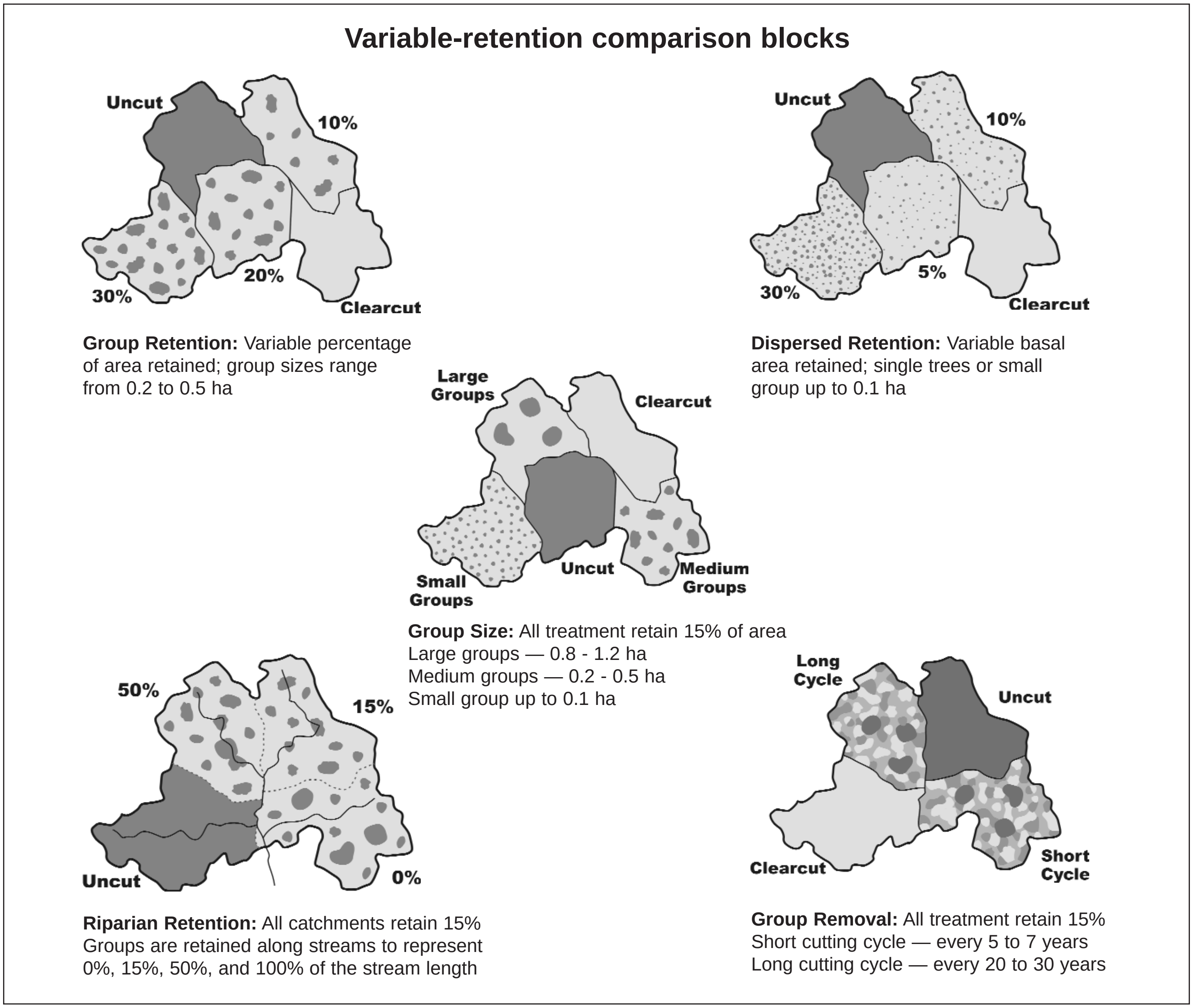

Figure 1—Diagram of variable-retention adaptive management experiments.

5. **Riparian retention:** 0 percent, 15 percent and 50 percent of the length of small streams within treatments are covered by group retention (i.e., 0.25 ha or larger groups); a retention level of 15 percent is maintained within all stream catchments.

Each VRAM block consists of five 20 ha treatments: three VR options, clearcut and uncut (fig. 1). Each VRAM site requires an area of 80 to 100 ha that is as uniform as possible in timber type, plant associations, and topographic features. Several cutblocks in close proximity can be used in place of a single contiguous area. Potential areas are evaluated for suitability by the science team. Forestry planners then complete a preliminary layout of treatment blocks. Treatments are randomly allocated to blocks before field layout commences. Regular communication occurs between the scientists and planners during layout to ensure that the objectives are met and the study design is not compromised. The 15 VRAM blocks are being installed by our six BC coastal timberlands units over a 7-year period as part of their annual harvest operations. At least of one the three sites for each comparison will be in an old-growth forest type.

Each of the VR options must meet the requirements of the "retention silvicultural system," which is the most common system used for implementing the variable retention approach. The retention system maintains enough tree canopy to have forest or residual tree influences on the majority of a cut area, and leaves long-term live and dead tree reserves of varying sizes and canopy layers, distributed throughout harvested areas (Forest Practices Code of BC Act 1999). Mitchell and Beese (2002) describe the retention system and its rationale as a silvicultural system. To simplify the operational implementation of the retention system, our company guidelines state that retained groups of trees should be greater than 0.25 ha in size and no more than 4 tree lengths apart; individual trees or smaller groups should be no more than 2 tree lengths apart. Consequently, no place within a cutblock is more than 2 tree lengths from some standing trees. These guidelines are flexible, but they ensure that retention is well distributed within a cutblock and that the forest influence criterion is achieved (Beese et al. 2003). The minimum group size ensures that understory habitat attributes are retained, such as undisturbed shrubs and mosses, and allows retention of dead trees with an unharvested buffer around them for worker safety.

The group removal comparison includes some additional specifications. Each group removal treatment retains 15 percent of the area in long-term retention. Harvesting of groups takes place over three passes at the prescribed intervals. In conventional terms, the short- and long-cycle treatments could be considered group shelterwood and group selection systems. Each treatment must have at least 3 examples of the following size classes per pass: 1.0, 0.5, 0.25 and 0.1 ha (a total of 9 each). Different sized groups must be intermixed throughout the block, not concentrated in one portion of the block. Other considerations for this treatment include planning for permanent access skid roads, felling snags in adjacent groups that could pose a danger to workers, orientation of groups to maximize light (north-south) and layout of groups to facilitate falling and yarding.

Development and implementation of VRAM experiments are overseen by two working groups. The VR working group, which is responsible for developing guidelines and recommending policies for VR implementation, consists of members from each timberlands unit and research specialists. Members chose which comparisons their unit would undertake in order to get a good distribution of blocks across site conditions on the BC coast. Timberlands track production and costs by treatment so that economic comparisons can be made. The adaptive management working group, which guides the implementation of the program, reviewed the experimental design and developed a framework for monitoring.

Structure Monitoring

Permanent transects are established in all VRAM treatment units to measure the following habitat elements:

- live trees (species, diameter, and height),
- snags (species, diameter, height, and decay class),
- coarse woody debris (species, diameter, and decay class),
- cover layers (canopy, small tree, shrub, herb, moss, litter, and mineral soil), and
- dominant shrub and herb species.

The sampling for dispersed retention cutblocks and the harvested portions of mixed retention blocks used 25 m x 25 m plots to measure live trees, nested within 50 m x 50 m plots in which snags and large trees were recorded. Coarse woody debris was measured along intercept transects of 50 m (for all sizes) or 100 m (for pieces >30 cm) on two perpendicular sides of the plot. Cover variables, dominant plants, and site series (plant associations) were recorded in five 0.01-ha circular sub-plots across the larger plot. Two plots were established per cutblock.

In areas with group and mixed retention, transects were used across the boundaries of retained patches, extending up to 50 m into the patch and 50 m into the opening. All trees within 2.5 m of the transect were recorded, as were all snags and large trees within 5 m. Coarse woody debris was recorded along both the main transect and 10-m-long transects running perpendicular to the main transect every 10 m. Trees, snags, and coarse woody debris were recorded separately in 10-m transect segments (i.e., 0–10 m from the edge, then 10–20 m, 20–30 m, etc.). Every 10 m along the main transect, 0.01-ha circular plots were used to assess cover layers, dominant plants, and site series. Two transects were established in each of three patches per cutblock.

Species Monitoring

The focus of species monitoring has been to evaluate a range of potential indicator or focal organisms for future monitoring. Obviously we cannot afford to monitor all species. There are about 200 vertebrates alone that potentially occur on Weyerhaeuser's BC coastal tenures (Bunnell et al. 1998). Nevertheless, monitoring indicator species will help us assess whether or not our strategies for leaving representative unmanaged areas and habitat structures actually result in productive populations of forest-dwelling species. Informative focal species are forest-dwelling, sensitive to

Table 1—Summary of operational and experimental monitoring

	Operational Monitoring						Experimental
Species group	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Monitoring**
Birds	X	X	X	X	X	X	X
Bryophytes	X				X		
Canopy epiphytes			X	X	X	X	X
Carabid beetles			X	X	X	X	X
Frogs and salamanders	X	X	X	X	X	X	X
Gastropods	X	X	X	X	X		X
Lichens		X					
Mycorrhizal fungi		X			X	X	X
Squirrels		X					
Vascular plants	X	X	X	X	X	X	X

forest practices, practical to monitor, and provide information that can guide management. Pilot studies in the first 5 years have included birds, vascular plants, bryophytes and lichens, mycorrhizal fungi, amphibians (frogs and salamanders), squirrels, terrestrial gastropods (slugs and snails) and carabid beetles. Pre- and post-harvest monitoring is occurring for some of these species on VRAM experiments; others are being evaluated in operational cutblocks (table 1). Executive summaries of species pilot studies and a series of technical project summaries describing objectives and methodology can be found on the Coastal Forest Strategy website (www.forestry.ubc.ca/conservation/forest_strategy).

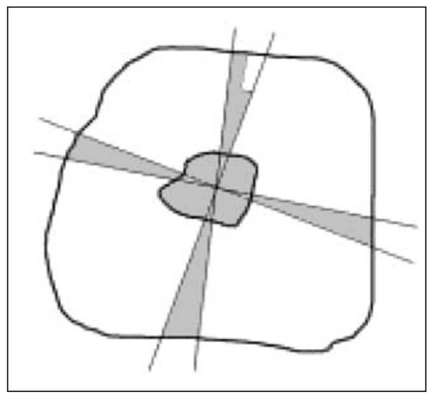

Figure 2—Layout of sector plots for growth and yield sampling. The shaded polygon in the center represents a retention patch. The pivot point of the four 9-degree sectors is located near the center of the patch.

Growth and Yield Monitoring

The company's growth and yield program is establishing permanent plots within VRAM areas. In each treatment, sector plots were established to collect growth data for both the leave trees and regenerating trees (planted and natural). Care has been taken to ensure that the same seed source/stock types are planted across the whole experiment. The approach uses a cluster of four sectors radiating from a central pivot point, the central axes of which are at right angles (fig. 2). For a 10-percent sample, each sector covers 9 degrees (for a total of 36° out of 360°). To sample a retained group of trees and the surrounding cut area, sector plots are located by selecting an arbitrary location within the group (usually the middle of the group of leave trees), then orienting the sectors from a random compass bearing. With this approach, the probability of selecting each tree in a sample is the same irrespective of the position of the chosen pivot point. By orienting the four sectors at right angles, a balance of aspects are sampled for examining edge effects. This is, as far as we are aware, a new sampling system which collects information in an unbiased fashion from retained groups and surrounding areas, correctly accounting for edge effects (Iles and Smith 2004). At least three sets of sector plots are established in each treatment replicate. A slightly modified approach is taken in clearcut and uncut areas to reduce sampling effort. The four sector clusters are collapsed into single 36° sector plots which are oriented randomly from the centre of randomly selected points on a 1-ha grid.

In order to increase our sample size for growth and yield data and cover more stand conditions than are possible in the 15 VRAM sites, we are establishing supplemental comparison sites with smaller size requirements, including mixed group-dispersed retention comparisons. These sites

Table 2—Characteristics and schedule for variable retention adaptive management experiments

Comparison	Location[a]	Forest type[b]	Elevation (m)	Harvest system[c]	Year
Group retention	NIT – Tsitika R.	1 – HwBaCw	550	Hoe	2001
	SWT – Goat Isl.	1 – HwBaYc	600	Hoe/Cable	2004
	QCT – Hoodoo	2 – SsHwCw	100	Hoe	2004
Dispersed retention	SWT – Horseshoe Lk.	2 – Fd	100	Hoe	2002
	TBA				2005+
	TBA				2005+
Group size	PMT – Cluxewe R.	2 – HwBa	100	Hoe	2002
	WIT – Klanawa R.	1 – CwHwBa	300	Cable/Hoe	2005
	TBA				2005+
Group removal	NIT – Memekay R.	1 – HwBaCw	700	Hoe	2004
	QCT – Crease	1 – SsHw	400	Heli	2005
	TBA				2005+
Riparian retention	SWT – Lewis L.	2 – FdHw	500	Hoe/Cable	2003
	NIT – Moakwa Cr.	1 – FdHwCw	450	Hoe	2004
	TBA				2005+

[a] NIT = North Island Timberlands, SWT = Stillwater Timberlands, QCT = Queen Charlotte Timberlands, PMT = Port McNeill Timberlands, WIT = West Island Timberlands

[b] 1 = old growth, 2 = second growth; Hw = western hemlock, Ba = amabilis fir, Cw = western redcedar, Yc = yellow-cedar, Fd = Douglas-fir, Ss = Sitka spruce

[c] Hoe = Excavator forwarding, Cable = grapple yarding, Heli = helicopter yarding

are operational cutblocks, but treatments are allocated randomly to portions of the blocks. Four have been established to date.

Windthrow Monitoring

Variable retention results in an increase in the total length of forest edge associated with cutblocks, as well as greater amounts of dispersed trees; consequently, we expect to see an increase in the frequency and extent of windthrow associated with harvesting in wind exposed areas. Our monitoring strategy is to document the extent of windthrow associated with VR on operational cutblocks as well as VRAM sites to gather data to improve cutblock design and windthrow management. All external edges, groups and patches, and dispersed trees within a treatment block are sampled. For external edges and larger groups, visual estimates of the amount of windthrow and depth of penetration are recorded the first 25 m into a stand edge. We chose to use stratified, unequal length plots to improve sampling efficiency and to ensure that any visible environmental differences that may exert a significant effect on windthrow response are sampled. Plot boundaries are determined by a change in stand conditions or environmental attributes such as soil type, slope morphology, surficial materials and boundary exposure. For small groups and dispersed trees we obtain a total count the number of standing and windthrown trees. VRAM sites are assessed in year 1, 3 and 5 post-harvest.

RESULTS

To date, four VRAM sites have been logged and four are scheduled for completion in 2004 (table 2). These sites cover a range of forest types from 100 m to 700 m elevation and are located on Vancouver Island, the Queen Charlotte Islands and the BC mainland coast. Half of the sites underway are in old-growth forests. The remaining seven VRAM sites are intended to be installed by 2007. Examples of group retention (fig. 3) and dispersed retention (fig. 4) were the first study areas completed in 2000 and 2001, respectively.

Figure 3—Aerial photo of a group retention experiment.

Figure 4—Aerial photo of a dispersed retention experiment.

At this point, we have few results to report from most established studies except documentation of preharvest conditions. We expect to obtain some useful results to inform variable retention practices by the fifth year after harvesting; however, many aspects of biological monitoring require longer timeframes for assessment of impacts. Monitoring species and forest structure are expected to provide data that will improve our habitat supply models (Dunsworth and Northway 1998).

Some of the initial findings from post-harvest monitoring include windthrow and forest structure. The group retention VRAM site in the Tsitika River valley experienced what was estimated as at least a 25-year storm in December 2001, the second winter after harvesting. Retained patches had windthrow damage ranging from 0 to 85 percent. As a result of the random allocation of treatments, the lowest retention level (10 percent) happened to coincide with the portion of the block most exposed to winds; consequently, this treatment area sustained the most damage.

Observations of windthrow throughout the area affected by the storm showed that damage appeared to have more to do with where the storm winds touched down than to the size or design of the block (Rollerson et al. 2002). The pattern of windthrow suggested undulating waves or cells of very strong winds that touched down periodically as the storm moved across the landscape. The storm affected ridges and valley bottoms as well as mid-slope positions. The storm damaged undeveloped old-growth and older second-growth stands (i.e., generally over 60 years old), the edges of clearcut and VR blocks, retention within blocks and other natural stand edges such as stream banks. Recently established plantations and younger second growth did not appear to suffer significant damage. Heavily damaged stands were found adjacent to areas with apparently similar conditions that were virtually untouched. Windthrow within VR groups or single tree retention was a relatively small proportion of the total forest damage caused by this storm. Within individual VR blocks, there was often a higher volume of windthrow associated with the external block boundary than with the groups left within the block

After 5 years, we have established structure monitoring plots in a total of 180 retention blocks, 56 benchmark (unharvested) sites, 20 blocks with riparian reserves and 9 older clearcuts including VRAM areas. Initial comparisons have assessed whether retention patches provide similar levels of habitat elements to those found in unlogged forests. Overall, retention tended to have lower levels of some important habitat elements, especially large trees and total basal area, than benchmark sites in the same biogeoclimatic unit (Huggard 2003). Snag density and basal area were similar, including size and decay class, for benchmark sites and retention patches. In some areas, however, tall snags were less common in retention patches. This tends to occur because of removal of hazard trees during logging operations. In drier ecosystems, retention tended to have more deciduous trees and snags than unlogged areas. The volume, composition and size distribution of coniferous woody debris tended to be similar for retention patches and unlogged stands. Although patches had lower canopy closure and shrub cover in some areas, there were no consistent differences in understory vegetation cover between benchmarks and retention patches.

SUMMARY AND CONCLUSIONS

Company biologists have formed partnerships with academic and government scientists to support the Coast Forest Strategy. Our AM framework outlines both operational and experimental monitoring activities (Bunnell et al. 2003). The operational monitoring examines structure, species presence and absence, forest growth, windthrow and forest health in current and future VR settings. Representation of ecosystems in unmanaged conditions is also being examined. The experimental portion of the AM program is focused on 15 VRAM study areas with comparisons designed to answer questions on the impacts of the amount, type, spatial and temporal distribution of retention.

Pilot studies were used to establish an appropriate sampling design and methodologies. Habitat structure including snags, coarse woody debris, live trees, and understory vegetation is being assessed in VRAM treatments, VR cutblocks and in unmanaged, benchmark forests. Studies on several organisms (breeding birds, gastropods, amphibians, bryophytes, lichens, squirrels, mycorrhizae, and carabid beetles) have been underway for various lengths of time. These studies are collecting baseline information to begin comparisons of the effectiveness of the various types of VR for maintaining biological richness. Initial findings have been used to examine how the results will link to management practices to strengthen areas that most need improvement.

Although use of the VR has become widespread in coastal BC, there is much we need to know about its potential impacts. Among the silvicultural challenges in implementing the retention system to meet biodiversity goals is predicting forest growth and inventory and managing future stand health. Forest managers and the public must seek to balance the benefits and costs as this new approach to silviculture is implemented and tested. Critical to the success of these new approaches is the design of cutblocks and stand entries to minimize impacts from wind damage. Losses from wind are unavoidable; however, the risks and economic impacts can be managed through planned salvage or retention of downed wood when it meets habitat objectives. Weyerhaeuser will continue to use both natural regeneration and planting to achieve diverse and valuable stand composition with the variable retention approach.

Future challenges include a reduction in our public forest landbase as a result of the BC government's reallocation of tenures, long-term funding commitments, and our ability to adapt our practices to meet changing goals and expectations. We have much to learn about forest ecosystems and new management techniques, but with the willingness to change, the open-mindedness to consider a wider range of forest values, and respect for worker safety we can leave a legacy in our forests for future generations.

ACKNOWLEDGMENTS

The authors thank the foresters, forestry engineers and planners, and forest workers on the BC coast for successfully taking up the challenge to implement variable retention and to do it safely. We thank the members of Weyerhaeuser's Variable Retention and Adaptive Management Working Groups, and specifically: Fred Bunnell, Laurie Kremsater, Dave Huggard, Ken Zielke, Bryce Bancroft, Jeff Sandford, Barb Knight and our enthusiastic field crews.

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Development of Stand Structure in Young Douglas-fir Plantations

Carrie A. Berger[1] and Klaus J. Puettmann[2]

ABSTRACT

Concerns about a landscape becoming dominated by stands in the stem exclusion phase led to initiation of a structure-based management study. The study documented the development of tree characteristics and understory vegetation, two aspects considered important for the diversity of plant and wildlife habitat. We measured conditions in 39 Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantations ranging from 6 to 20 years in three districts in western Oregon. Results confirmed intuitive trends and quantification indicated that some trends develop earlier than commonly assumed. Tree growth in young stands was positively related to stand density early on, but this trend reversed fairly quickly. Crown size was reduced very early in higher density stands and crown recession increased with age. Understory herb cover was reduced over time, while shrub cover increased. Species compositions were quite complex, with an initial strong presence of invasive species and later dominance of species usually associated with mature forests.There were many exceptions, however, and early successional species were still present after 20 years.

KEYWORDS: Density management, stand initiation phase, crown characteristics, understory vegetation.

INTRODUCTION

Although a large portion of the western Oregon forests are now occupied by dense Douglas-fir plantations (*Pseudotsuga menziesii* (Mirb.) Franco), analysis of early growth rates in old-growth stands in the Oregon Coast Range indicated that these stands may have initiated at lower densities than commonly found in current plantations. This implies that these stands may have never gone through a classic stem exclusion phase (Poage and Tappeiner 2002, Tappeiner et al. 1997), and the range of natural variability in western Oregon forests included open conditions in young stands. This raises the question whether the current, dense plantations will develop efficiently into forests that provide late-successional habitat. Several studies (for examples, see Monserud 2002) have focused on the later stages of the stem exclusion phase; this study, therefore, focuses on the regeneration establishment phase to investigate whether undesirable aspects of the stem exclusion phase can be prevented or lessened through density management. The objective of this study was to characterize development of stand structure and to explore different pathways to manage young Douglas-fir plantations for a combination of older forest structures and revenue production.

METHODS

Using a chronosequence approach, we selected 39 Douglas-fir plantations from 6 to 20 years in three Oregon Department of Forestry (ODF) districts (Astoria, Forest Grove, and Philomath) in the *Tsuga heterophylla* zone (Franklin and Dyrness 1973) in the middle to northern part of the Oregon Coast Range. For a more detailed description, see Puettmann and Berger (in prep.). Three transects were laid out in each plantation to capture variability. A transect typically consisted of three circular plots (5-m radius) established at variable distances with similar slope and aspect, that differed in overstory densities. Overstory

[1] Faculty Research Assistant and [2] Associate Professor, Oregon State University, Department of Forest Science, 321 Richardson Hall, Corvallis, OR 97331-5752, USA. Email for corresponding author: carrie.berger@oregonstate.edu

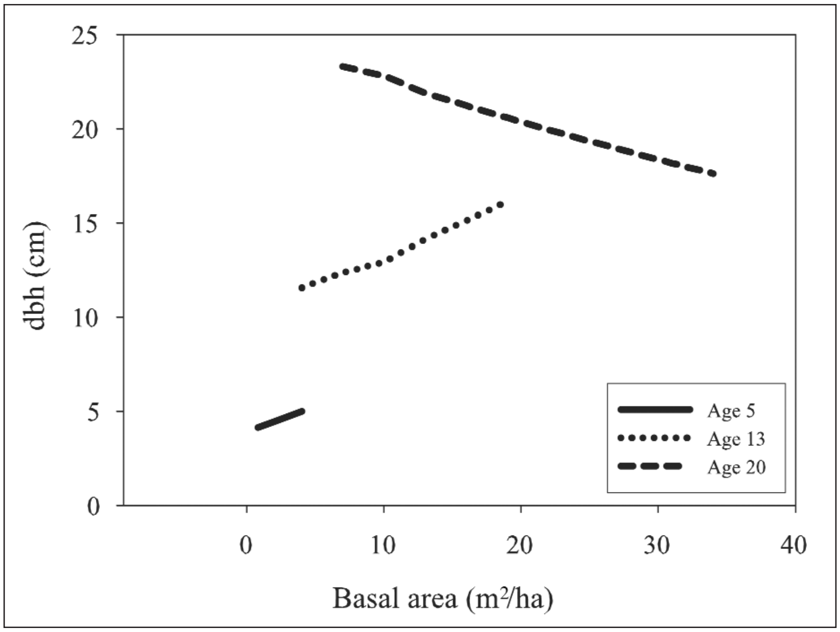

Figure 1—Diameter at breast height for the Philomath district as a function of stand basal area. Initially crop trees showed better growth in stands with higher basal area; however, this trend was reversed by age 20. Lines represent different ages.

densities on each transect included a low (gap, ~1-3 crop trees/plot), medium (transition or low density, ~3-4 crop trees/plot), and high (matrix or fully stocked, ~4-6 crop trees/plot) density condition that were selected by observational assessment of tree densities. Within this constraint, a 5-m radius plot was randomly located in each overstory density condition. Crop tree selection included all planted trees and naturally regenerated trees that had dominant positions.

Tree and crown characteristics and understory vegetation data were analyzed by using a mixed model that included basal area, site index (King 1966), and age as main effect terms (fixed factor), and the interaction between basal area and age. Plantation identification and transect within plantation identification were random factors. Total basal area was used because it accounts for the numbers and sizes of all trees. Prior to analyses, means were calculated for each tree plot. Percentage of cumulative cover for forbs and shrubs was calculated by adding up percentage of cover by individual species to account for multiple layers of species in a plot.

RESULTS AND DISCUSSION

Initially crop trees showed better growth in stands with higher basal areas in all three districts (for example, see Philomath in fig. 1), although the Forest Grove district showed no height response. However, density had a negative effect on diameter at breast height, height growth, and crown radius in older stands, and the initial growth trend was reversed before age 20. Crown recession, due to branch mortality, was evident in the early stages of growth and increased with age. Higher densities also reduced diameter and length of the lowest live branch. (Note, a positive relationship between density and diameter and length of lowest live branch was found in Forest Grove.) Tree size and crown characteristics, i.e., crown and branch size, are important stand structural components and early stand management in dense plantations is crucial to maintain these components. For example, wider planting spacing or early precommercial thinnings are necessary to ensure development of large, low branches that are important habitat component for mosses, lichens, and other species (McCune et al. 2000). These trends were independent of site quality.

High overstory densities were indicative of lower forb and shrub cover in Philomath and Astoria. In both districts, shrub cover was greater on high quality sites, suggesting that resource limitations may be responsible for this trend. Only in Philomoth did shrub cover increase with age (fig. 2). Conversely, high overstory density stands in Forest Grove were correlated with low shrub cover with no recovery over time. Apparently understory conditions in Forest Grove are

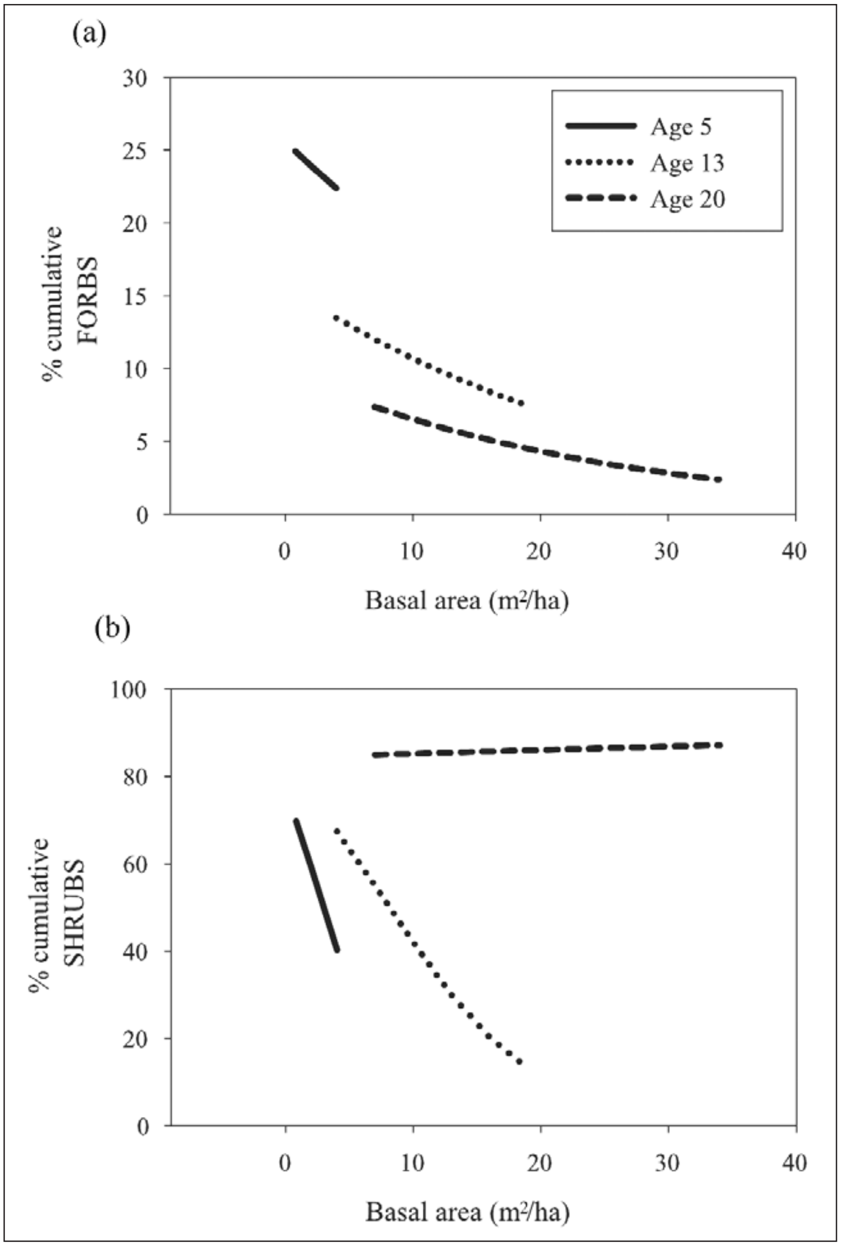

Figure 2—Forbs (a) and shrubs (b) for the Philomath district as a function of stand basal area. Higher densities were indicative of lower forb and shrub cover; however, shrub cover increased with age. Lines represent different ages.

influenced by other factors, such as previous weed control treatments. At this stage in stand development, shrubs and forb coverage was very stable and did not change over time.

Overall, composition of understory vegetation was quite variable. We used the criteria as described by Halpern (1989) to differentiate invasive and residual species. Within both groups we found species with different response patterns, from species with slow rates of occupancy (e.g., *Agoseris* spp., *Cirsium* spp., and *Rubus leucodermis*) to species that experienced a shift from increasing to decreasing occupancy (e.g., *Rubus parviflorus*, *Pteridium aquilinum*). The same variability was found for residual species. For example, *Acer circinatum*, *Berberis nervosa*, *Corylus cornuta*, and *Polystichum munitum* were present after the previous harvest and showed continuous recovery on our study sites and even became dominant features in fairly young stands (>12 years). On the other hand, other residual species (e.g., *Rubus ursinus*) were persistent in all cohorts but decreased in occupancy in the older stands. In addition, invasive and residual species were all major contributors throughout the 20-year period.

Our results indicated that stand development as characterized by tree characteristics and understory vegetation is influenced by density early on and is very dynamic in young plantations. The development of understory vegetation was highly variable and likely a function of preharvest stand conditions, harvesting damage, invasion, and recovery. Maintaining or enhancing existing low-density areas in young plantations may enable diverse within-stand conditions that affect development of stand composition and ecosystem function while at the same time allowing flexibility in management of high density areas for different purposes, e.g., timber production.

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Blending Stand-Level Treatments and Landscape Planning with Opportunities for Research in a Working Forest

Jeff A. Boyce[1]

ABSTRACT

Two contrasting approaches for managing forest stands on Throne Island in southeast Alaska were developed as part of the Lab Bay Timber Sale Environmental Impact Statement (EIS) (USDA FS 1997a). The primary purpose for developing the management plans was to provide timber for the local economy as allowed under the existing forest plan (USDA FS 1997b). A secondary purpose was to address the physical, biological, and social issues concerning timber harvest on the island.

A conventional harvest plan would develop a log transfer facility, a road network, and use cable logging systems to clearcut harvest 2 to 24 hectare (ha) units. The nonconventional harvest plan proposes harvesting 109 units, each 0.8 ha in size, in a scattered, irregular distribution across the productive forest land on the island. Helicopter harvesting techniques would be used to minimize infrastructure development on the island. This management plan contrasts with a conventional harvest approach where a network is developed and cable skyline systems are used. A possible benefit for selecting this nonconventional harvest plan includes the opportunity to conduct landscape and stand-level ecological studies within the existing framework and management of a working forest. Research studies on Thorne Island will provide results applicable to other working forests in southeast Alaska.

KEYWORDS: Southeast Alaska, adaptive management, landscape planning.

INTRODUCTION

Two contrasting approaches for managing forest stands on Throne Island in southeast Alaska were developed as part of the Lab Bay Timber Sale Environmental Impact Statement (EIS) (USDA FS 1997a). The primary purpose for developing the management plans was to provide timber for the local economy as allowed under the existing forest plan (USDA FS 1997b). A secondary purpose was to address the physical, biological, and social issues concerning timber harvest on the island.

A conventional harvest plan would develop a log transfer facility, a road network, and use cable logging systems to implement clearcut harvest of 2 to 24 ha units. The nonconventional harvest plan proposes harvesting 109 units, each 0.8 ha in size, in a scattered, irregular distribution across the productive forest land on the island. Helicopter harvesting techniques would be used to minimize infrastructure development on the island. This management plan contrasts with a conventional harvest approach where a road network is developed and cable skyline systems are used.

This paper outlines and compares the differences between a conventional and nonconventional harvest method by addressing such issues as proposed harvest (area and volume), proposed road construction, development of log transfer facilities, economics, and the effects to noncommodity resources. This information was used to select a harvest design program for the Thorne Island timber sale project.

[1] Forest Ecologist, Meridian Environmental, Inc. 1900 N. Northlake Way, Suite 211, Seattle, WA 98103, USA. Email: jboyce @meridianenv.com

PROJECT LOCATION

The Thorne Island project area is located on the Tongass National Forest in southeast Alaska, approximately 113 km northwest of Ketchikan. Thorne Island is part of the Alexander Archipelago, a group of islands composing southeast Alaska and coastal British Columbia. It is located near the southern end of the archipelago, east of Prince of Wales Island, one of the largest islands in the archipelago. A cool, moist maritime climate dominates the region, producing western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), and Alaska yellow-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) forest vegetation types interspersed with nonforested peatlands. The Lab Bay EIS planning area includes Thorne Island and approximately 81 000 ha of additional forest land at the northern end of Prince of Wales Island that was evaluated for timber sale opportunities.

EXISTING CONDITIONS ON THORNE ISLAND

Thorne Island is roughly circular in shape and 2952 ha in size. Geographic information system (GIS) data shows that 1235 ha of the island are considered suitable for timber harvest, 11 ha of which have been previously harvested. There are no roads, log transfer facilities, or other development on the island, and previous timber harvest has been limited to a few small areas along the shoreline. The island is southeast of the small community of Whale Pass and is commonly used by residents for subsistence hunting and recreation. The perimeter landscape of the island is visible from recreational and small, commercial marine traffic. The interior landscape of the island is generally only visible from the air and may be seen by passengers of float planes providing service to the adjacent community.

TIMBER SALE PLANNING

The initial harvest plan for Thorne Island included two design options: a conventional road and clearcut harvest unit design, and a nonconventional distributed patch-cut, helicopter logging design. Table 1 shows summary information for each of the harvest designs.

The conventional harvest design included the development of a log transfer facility on the western shore of the island and approximately 25 km of new road construction to access proposed harvest units. Nineteen units would be harvested with unit sizes ranging from 2 to 24 ha. Cable yarding systems would be required in most units to move logs from the stump to the road. A total of 251 ha would be harvested during the first entry, providing a harvest volume of 8.9 million board feet. Due to the initial cost of infrastructure development, a greater proportion of volume would be harvested during the first entry than in subsequent entries. Four subsequent harvest entries would be planned over a 135-year period.

The nonconventional harvest design included the proposed harvest of 109 group selection units in a scattered, irregular distribution across the forested landscape. Each unit would be 0.8 ha in size and include the retention of some trees to provide structural diversity over the life of the new stand. Approximately 3.9 million board feet could be harvested in the first entry, with subsequent entries occurring at 15-year intervals over the next 135 years. A helicopter yarding system would be used to transport logs from the stump to barges anchored offshore. The development of a log transfer facility and road network would not be necessary to implement this harvest design.

Timber sale planning on National Forest System land is conducted according to the environmental assessment guidelines of the National Environmental Policy Act (NEPA). NEPA regulations (40 CFR 1501.7) require the evaluation and disclosure of the potential effects of implementing a proposed action, and alternatives to the proposed action, on the physical, biological, and social resources of the area. This evaluation is used by Forest Service decisionmakers to select a preferred project alternative for implementation.

Environmental analysis of the harvest design options for Thorne Island included an evaluation of the physical and biological effects, and a comparison of short-term and long-term project costs and benefits. The nonconventional harvest design was expected to minimize the permanent disturbance of physical resources on the island, and maintain visual resources, vegetative diversity across the landscape, wildlife habitat, and existing subsistence values. Economic and management factors were also considered in determining which harvest design option would be selected in the Record of Decision for the Lab Bay timber sale EIS project. Economic concern for the nonconventional harvest plan focused on the estimated appraised value of the sale and whether local purchasers would consider the timber sale economically feasible. Management concern for the nonconventional harvest plan focused on the ability to efficiently implement the sale layout and harvesting operations.

ECONOMIC EVALUATION

The first measure of economic feasibility of the nonconventional harvest plan was identified during field studies

Table 1—Comparison of harvest plan attributes and costs

First entry	Conventional harvest design	Nonconventional harvest design
Quantities		
Proposed harvest (ha)	251	88
Proposed harvest volume (mbf)	8,961	3,922
Proposed road construction (km)	25	0
Number of log transfer facilities	1	0
Total cost/MBF	$427	$380
Subsequent entries	4 additional entries over a 135-year period	9 additional entries over a 135-year period
Quantities		
Total proposed harvest (ha)	718	794
Total proposed harvest volume (mbf)	31,914	35,298
Total proposed road construction (km)	14.5	0
Proposed road reconstruction (km/entry)	18	0
Number of log transfer facilities	0	0
Total cost/mbf	$222	$380
Total costs over a 150-year rotation (in constant dollars)		
Total cost	$10,910,561	$14,903,600
Total cost/mbf	$267	$380

mbf = thousand board feet

conducted for the conventional harvest plan. The stand exam showed that Thorne Island had a greater composition of cedar species than the remaining portion of the Lab Bay Timber Sale project area. Western redcedar (*Thuja plicata* Donn ex D. Don) composition on Thorne Island was estimated at 14 percent whereas the composition of Alaska yellow-cedar was 49 percent. The higher selling value of cedar products, compared to other species, would increase the appraised value of the proposed sale.

The estimated costs of implementing each harvest plan are shown in table 1. Costs for the initial entry are identified separately from all subsequent entries to show the influence of road network development and logging systems on the cost of each harvest plan. Costs are estimated for all entries occurring over a 150-year period, resulting in the harvest of approximately 40 million board feet. The total revenue associated with each plan is assumed to be relatively similar, with differences only in the timing of the revenue stream. Over the entire rotation period, the cost of the nonconventional harvest plan will exceed the conventional harvest plan by approximately $4.0 million. Assuming that Forest Service decisionmakers select the nonconventional harvest plan as a result of the environmental assessment and public involvement process, the difference in total cost between the two plans represents the public value of the noncommodity amenities and uses of Thorne Island.

Figure 1 shows the historical market cycle for a composite index of 1000 board feet of wood products sold on the Tongass National Forest and the discounted value of the bid price for the nonconventional harvest plan. The composite index is based on the weighted average species composition present on Thorne Island and, therefore, represents the estimated value of the products that could be produced from the timber on Thorne Island. The discounted bid value is based on the purchasers competitive bid price for the nonconventional harvest plan. The bid value is discounted back through the historical value of the composite index. This figure shows that through most of the recent wood products market cycle, the purchase price of the nonconventional harvest plan is lower than the composite market index value on many occasions. This indicates that there are opportunities for positive economic returns available to purchasers of timber sales with nonconventional harvest designs during part of the market cycle. Timber sales prepared following nonconventional harvest designs are not fundamentally uneconomical because of their higher costs;

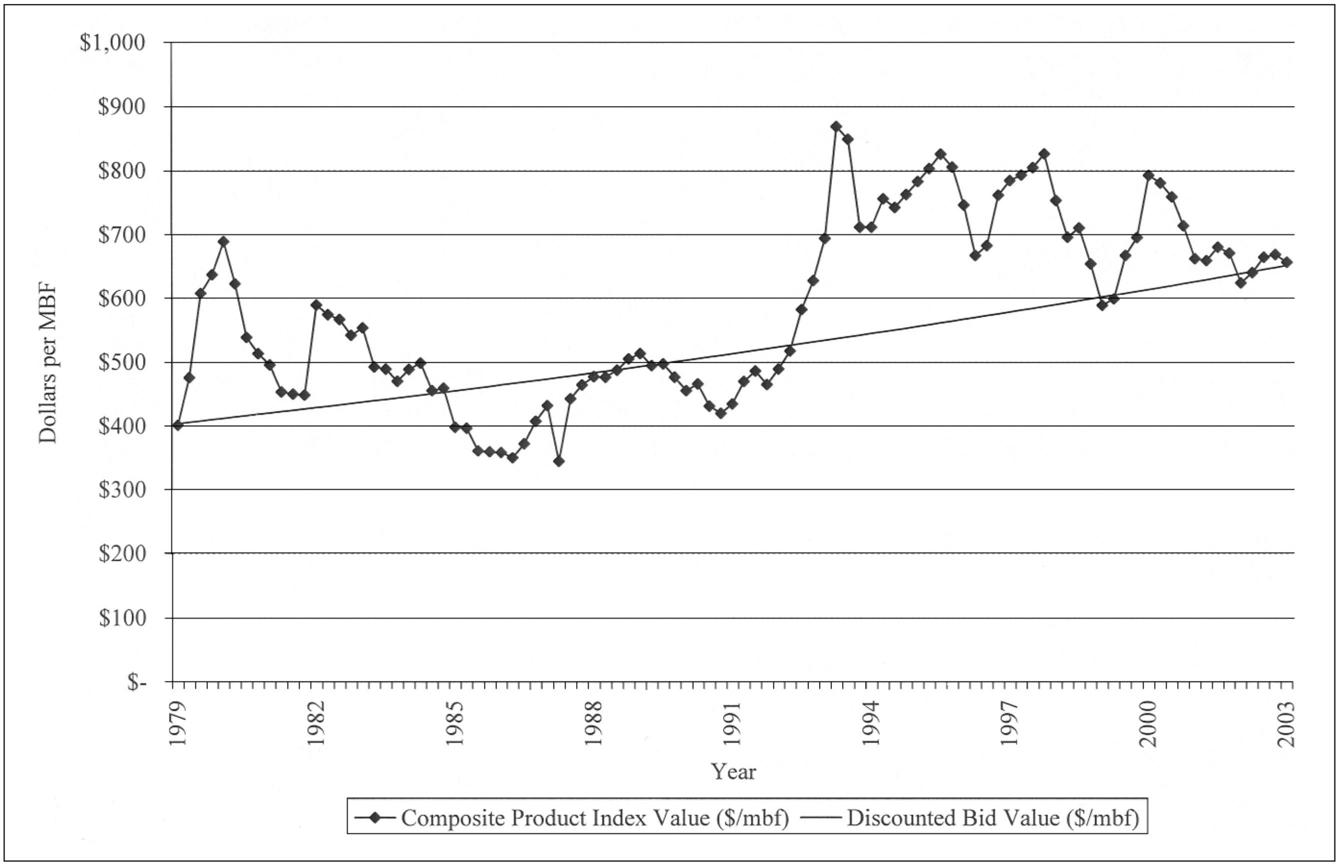

Figure 1—Historical market cycle (weighted by species composition).

the break-even value for a purchaser depends on the species product values in the regional market.

MANAGEMENT EVALUATION

The logistics of implementing the nonconventional harvest plan was a concern for the local forest managers. They were concerned about potentially higher costs to complete final sale layout tasks, the standards for documenting the sale area, and the ability of logging crews to efficiently find the unit locations. Through discussions between the local forest managers and the sale planners, techniques were identified for completing the sale layout tasks efficiently while providing clear identification of each harvest unit that would last until logging crews began sawing, possibly several years after the completion of sale layout tasks.

The nonconventional harvest design was selected in the final EIS for implementation on the basis of minimizing the environmental effects of harvest while providing an economically feasible timber sale for the local economy.

THE EVOLUTION OF A TIMBER SALE

Changes in the Tongass Land Management Plan (USDA FS 1997b) after completing the initial sale design reduced the total forest land available for timber harvest on Thorne Island. Harvest units could no longer be placed within 305 m of the shoreline, and a small old-growth reserve was created to protect sensitive wildlife habitat. These changes required the recalculation of the total number of 0.8 ha units proposed for harvest, and a redistribution of the units to be harvested. The recalculation of the harvest design allowed for the placement of 90 harvest units on the island.

The location of the 90 proposed 0.8 ha harvest units were identified using a GIS automated process. A 0.8 ha grid coverage was overlaid onto the suitable and available forest land and used to identify individual units for harvest. An automated procedure was developed in GIS to select the proposed harvest units based on the rotation length and the re-entry interval for the island. The GIS procedure identified every tenth grid square overlaying suitable forest land as a harvest unit. Because nonsuitable forest land was intermingled throughout the island, the visual pattern of harvest would be represented by a scattered, irregular distribution across the landscape.

During final sale layout, minor adjustments were made to the location of some harvest units to protect previously unmapped streams. In addition, the old-growth reserve was expanded to account for the discovery of new nesting and denning areas for sensitive wildlife species. Ninety harvest units were delineated on the ground to produce an estimated harvest of 3.0 million board feet.

The preparation of the timber sale package resulted in further adjustments to the selection of units proposed for harvest. Forest managers anticipated low interest in the sale due to the reliance on helicopter harvesting techniques. Changes to the final sale offering were proposed that reduced the number of harvest units with the longest yarding distances, thereby increasing the logging efficiency and reducing the total logging costs. In addition, individual harvest units were evaluated for species composition in an effort to increase the weighted average value per hectare for the sale. The timber sale contract was drafted to allow the retention of western hemlock trees identified during cutting with a high proportion of decay. These changes would improve the economic viability of the sale, while increasing the retention of trees for wildlife habitat and visual screening. In the final sale offering, 55 harvest units remained in the timber sale area, providing an estimated 1.8 million board foot harvest.

The Thorne Island timber sale was purchased by a local forest product manufacturer in the spring of 2004. The contract terms require the completion of the timber harvest by the fall 2005.

OPPORTUNITIES

Although the selection of harvest units was modified throughout the timber sale planning and implementation process to account for environmental factors and economic conditions, the goal of the nonconventional harvest design remained constant: provide a feasible timber sale to the local forest products industry with a minimum of long-term effects on the environmental and social resources of the island.

The final distribution of harvest units includes a range of site conditions (e.g., site index, plant association, soil type, aspect, windthrow risk, etc.) that are represented on the island. The location of harvest units across the landscape retained the scattered, irregular distribution of the original harvest design, although units in the central portion of the island were dropped from the final sale offering.

The number of harvest units and their distribution across the landscape provide an opportunity to meet research study design criteria for replication that is often not available from conventional harvest practices in a working forest. The inclusion of replication into the harvest design provides a unique opportunity for reducing environmental variability in research studies conducted on the island. Environmental studies on Thorne Island will contrast with other studies conducted in areas using conventional road development and clearcut harvesting practices. Other interesting opportunities discussed for Thorne Island include the completion of time and production studies to provide additional information regarding the production rates and costs of helicopter logging systems in southeast Alaska.

CONCLUSION

The development and implementation of the nonconventional timber sale for Thorne Island represents a policy of adaptive management. This concept developed by Walters (1986) and discussed by Lee (1993) promotes the identification and implementation of nonconventional management policies as a test against which our current policies can be compared. An important element of adaptive management is the identification and planning of an alternative resource management policy, which when implemented provides a distinct outcome for an alternative management hypothesis. The monitoring and evaluation associated with implementing nonconventional management policies contrasts with conventional resource management policies, and either confirms or denies hypotheses about alternative management policies. The Thorne Island harvest plan includes the planning elements of adaptive management that will allow forest managers to obtain a greater understanding about the management of natural resources on the Tongass National Forest.

A benefit of implementing the nonconventional harvest design includes the opportunity to conduct landscape and stand-level ecological studies within the existing framework and management of a working forest. As additional studies develop on Thorne Island to monitor the response of ecological conditions to the nonconventional harvest design, the adaptive management process will continue. The information obtained through research studies will provide results applicable to other working forest in southeast Alaska.

The physical characteristics of Thorne Island are well suited for the nonconventional harvest plan. The circular configuration of the island and the opportunity to helicopter yard logs to offshore barges requires minimal infrastructure development on the island and produces an economically feasible project. Opportunities may be available in other areas of the western United States and Canada to design similar landscape plans to achieve environmental and social goals. Forested areas along scenic highways or river corridors that have high visual constraints may be candidates for a similar style of landscape plan. This style of harvest design provides an opportunity to continue harvest activities in these areas rather than transferring them to other land use designations containing prohibitions on harvest.

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