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Proceedings: Views From the Ridge—Considerations for Planning at the Landscape Scale

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Proceedings: Views From the Ridge—Considerations for Planning at the Landscape Scale

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Editors

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Abstract

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When resource managers, researchers, and policymakers approach landscape management, they bring perspectives that reflect their disciplines, the decisions they make, and their objectives. In working at a landscape level, they need to begin developing some common scales of perspective across the variety of forest ownerships and usages. This proceedings is a compilation of 22 papers presented at a conference that addressed divergent views on landscape management. The conference was a forum for exchanging concepts and knowledge from research and management experiences about managing landscapes. The program addressed the issues of managing landscapes when everyone has a different perspective; approaching landscape management from aquatic, terrestrial, and socioeconomic viewpoints; and characterizing landscape management.

Keywords: Landscape management, forest policy, forest management, aquatic, terrestrial, socioeconomic.

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Introduction

Hermann Gucinski[1]

Fred Swanson, a scientist who has devoted much of his career to the study of the processes that affect the character of a landscape, was asked while leading a tour of the H.J. Andrews Experimental Forest in Oregon with the group poised atop a commanding ridge, “Well, just what **is** a good landscape?”

As a scientist committed to expanding knowledge rather than to just citing known facts, he took this question as a serious challenge, admitted to finding it perplexing, and used it in turn to engender deep discussion, and some introspection, around the campfire that evening.

Before we can use the same question as a framework for the contributions in this volume, it might be good to ask: “What is a landscape?” and, because this is a scientific endeavor, “What is landscape ecology, and how might it contribute toward the larger question?” For it was indeed the objective of the symposium, and the proceedings that resulted, to take the “View From the Ridge” as a scientific challenge, rather than a subjective one, and to try to learn if a scientifically framed answer can also help with the subjective part of the needed answer.

Webster’s unabridged dictionary and the *Oxford English Dictionary* have similar definitions: “a portion of land or territory, which the eye can comprehend in a single view, including all the objects so seen” for the former, and “a view or prospect of natural in-land scenery, such as can be taken in at a glance from one point of view; a piece of country scenery” for the latter. Both offer some additional definitions: “a tract of land with its distinguishing characteristics and features, esp. considered as a product of modifying or shaping processes and agents (usually natural)”—“a view, prospect *of* something”—“a distant prospect: a vista,”—“a bird’s-eye view; a plan, sketch, map.” Thus, our title, “Views From the Ridge” is appropriate, although one contributor, Bob Ziemer, astutely notes that a “view from space” would provide a yet larger prospect (“Vogelschau” [bird’s-eye view] may be the most apropos German word for this), whereas “a view from the valley” would help discern the delivery of results from upland processes when taking an aquatic or riparian perspective.

These processes, the delivery of mass and energy, among others, bring us to the scientific part of the inquiry—the appropriate subject of “landscape ecology.” Richard T.T. Forman and Michael Godron (1986) used this definition in their seminal work:

> Landscape ecology is the study of structure, function and change in a heterogeneous land area composed of interacting ecosystems. It therefore focuses on:
>
> - structure, the spatial patterns of landscape elements and ecological objects (such as animals, biomass and mineral nutrients);
> - function, the flows of objects between landscape elements; and
> - change, alterations in the mosaic through time.

Monica Turner (1989) defines it thus:

> Landscape ecology emphasizes the interaction between spatial pattern and ecological process—that is, the causes and consequences of spatial heterogeneity across a range of scales. Two important aspects of landscape ecology distinguish it from other subdisciplines within ecology. First, landscape ecology explicitly addresses the importance of spatial configuration for ecological processes. Not only is landscape ecology concerned with how much there is of a particular component but also with how it is arranged. Second, landscape ecology often focuses upon spatial extents that are much larger than those traditionally studied in ecology.

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The following papers show the interest focused on the importance of spatial configuration for an ecological process and will demonstrate the astonishing variety of both viewpoints and scales used to address problems. This shows the science to be evolving and is a sign of the value placed on problems in this area. A brief look at the history of forestry science shows its earliest endeavors, silviculture and entomology, to be largely driven by stand-scale processes. Problems were considered solvable at that scale. Not only that, but the nature of the problem and suggested solutions were seen as largely separable. You isolated each variable, and treatments of that variable were based on the discipline within which it fell. Although this is oversimplified, earlier scientific endeavors engendered the separation of the disciplines and slowed understanding of the interdependence of ecological processes. "If all you have is a hammer, every problem will begin to resemble a nail." This approach worked for a long time.

Many phenomena contributed to the expanding view of ecological processes. We recognized that the accumulation and translocation of long-lived pollutants required a comprehensive look at biological, hydrological, and atmospheric processes. So did the need to develop concepts of "carrying capacity" as the pressures of nonsustainable resource use—hastened by population growth—brought conditions that could no longer be described or understood at stand levels. This development challenged resource managers to abandon linear approaches to management—ecological processes are cyclical in nature, and evolutionary development has allowed highly integrated system functioning that produces no waste. Superimposing solutions based on linear thinking caused new problems to pop up in places outside the scientific discipline where the original problem first appeared. Addressing the consequences resulted in yet other problems, leading to a vicious circle of "stimulus-response."

That dynamic can be broken by moving up in scale from the domain of the initial problem, seeking to understand the connections while standing on the ridge—or, alternatively, in the valley. This can help us regain perspective, and find pathways to solutions. Dale and Noon tackle this by relating the view from the ridge to a quite specific ridge, namely Oak Ridge, site of the Oak Ridge National Laboratory and its rich history of contributions to landscape ecology. Today's efforts are enhanced by better tools and methods, as Spies notes in his contribution, and they also require looking beyond political boundaries such as ownerships. McGaughey introduces us to valuable visualization tools now available to permit examination of landscape "treatment" scenarios. Raphael argues that being able to hold onto all scales is a necessity when considering the problem of "viability" of a species that is threatened. Clark et al. wrestle with the subjective components of a landscape as they relate to the values that people assign to it. And, as Shindler reminds us, right up to the present, our decisions have almost always been made at the stand level. Morgan expands our vista to not only view a landscape in space, but become aware of it over time such as a knowledge of history permits. Here the concept of "historical range of variation" can be a vital tool. Benda and Miller take landscape processes under the lens, focusing on the differences between stochastic and deterministic processes. Confusing these can have disastrous consequences. Neilson reminds us of the nature of "emergent properties" when going to a larger scale, and uses climate response as a useful integrator for these processes.

The intent here is not to give away the principal theses and conclusions of each contributor. Instead, I want to whet the appetite of the reader, convey the breadth and depth that are contained in this volume, reflect on the variability of the approaches outlined, and weigh their implications. Finally, I hope the information given and the challenges raised will encourage the reader to rethink the question, "What is a good landscape?" in light of available science as it illuminates the subjective needs we have.

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Conference Overview

From Red Queens to Mad Hatters—A Wonderland of Natural Resource Management

Lance Gunderson[1]

Lewis Carroll (1899) created a number of memorable characters who appear and reappear throughout the adventures of *Alice in Wonderland*. A few of these characters highlight and resonate with my sense and experience of the kinds of issues faced by resource managers. Just as Alice is bewildered by the complexities and uncertainties of Wonderland, managers often face similar issues of sensemaking and coping with the inevitable surprises of complex systems of humans and nature. In the following sections, I use these rich characters from Wonderland as an entree into a set of topics that will hopefully stimulate some ideas related to the paradigms that underlie our management of natural resources at the landscape scale, beginning with the Red Queen.

Red Queens and Other Caricatures

> "Well, in our country," said Alice, still panting a little, "you'd generally get to somewhere else—if you ran very fast for a long time, as we've been doing."
>
> "A slow sort of country!" said the Queen. "Now, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!"
> ……..Lewis Carroll

The Red Queen's action depicted in this scene is often used as a metaphor by evolutionary biologists to describe whether species can adapt to rapidly changing environments. I see similar "Red Queen dilemmas" as practitioners work as fast as they can to cope with rapidly and unpredictably changing systems. This metaphor can be extended to include a wider set of assumptions or myths that help to explain how nature operates. Each of these myths has a different supposition of how stable systems are (in the sense of responding to perturbations over time), the types of processes that support that stability domain, consequences of those assumptions, and explanations for policy and action. At least five such caricatures are described in the following paragraphs (modified from Holling and Gunderson 2002).

Nature Flat

Although this perception is perhaps so simplistic as to be silly, it is included here as a starting point from which subsequent contrasts with other views can be made. In this view, the word "flat" is used to describe a system in which there is little or no stability of structure over time. The hands of humans, given sufficient resources can change nature, and there are no feedbacks or consequences of those actions—it is much like rolling a ball around on a cookie sheet. The processes that affect the state of nature are random or stochastic. In such a view of nature, policies and politics are random as well, often described as garbage can dynamics (March and Olsen 1989). It is a nature that is infinitely malleable and amenable to human domination. As such, the issues of resource use, development, or control are identified as issues of people and resolved by activism or community organization.

Nature Balanced

The second is a view of nature at or near an equilibrium condition, which can be static or dynamic. Hence if nature is disturbed, it will return to an equilibrium through (in systems terms) negative feedback. As such, nature seems to be infinitely forgiving. This is the view of nature that underpins logistic growth where the issue is how to navigate a looming and turbulent transition—demographic, economic, social, and environmental—to a sustained plateau. This is the view of several institutions with a mandate for reforming global resource and environmental policy: the Brundtland Commission (Brundtland and Khalid 1987), the World Resources Institute, the International Institute of Applied Systems Analysis (Clark and Munn 1986), and the United Nations (Munasinghe and McNeely 1995) for example, who are contributing

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skillful scholarship and policy innovation. They are among some of the most effective forces for change.

Nature Anarchic

If the previous myth is one where the system stability is defined as a ball at the bottom of a cup, this myth is one of a ball at the top of a hill. It is globally unstable. It is a view dominated by hyperbolic processes of growth and collapse, or where increase is inevitably followed by decrease. It is a view of fundamental instability where persistence is only possible in a decentralized system with minimal demands on nature. It is the view of some extreme environmentalists. If the previous view assumes that infinitely ingenious humans do not need to learn anything different, this view assumes that humans are **incapable** of learning. This is implicit in the writings of Tenner (1996), where he argues that all technology that is unleashed will eventually "bite back." This view presumes that small is beautiful because of the inevitable catastrophe of any policy. It is a view where the precautionary principle dominates policy, and social activity is focussed on maintenance of the status quo.

Nature Resilient

The fourth view is of nested cycles organized by fundamentally discontinuous events and processes. That is, there are periods of exponential change, periods of growing stasis and brittleness, periods of readjustment or collapse, and periods of reorganization for renewal. Instabilities organize the behaviors as much as do stabilities. This has recently been the focus of fruitful scholarship in a wide range of fields—ecological, social, economic, and technical. These dynamics have similarities in Harvey Brook's view of technology (1986), Brian Arthur's and Kenneth Arrow's recent views of the economics of innovation and competition (Waldrop 1992), Mary Douglas' (1978) and Mike Thompson's (1983) views of cultures, Don Michael's view of human psychology (1984), and Barbara Tuchman's (1978) and William McNeill's (1979) views of history. The "nature resilient" view is a view of multiple stable states in ecosystems, and management approaches that are adaptive. But both of these presume a stationary landscape. In this case, our cookie sheet has been molded and curved in three dimensions, but it is fixed over time.

Nature Evolving

The emerging fifth view is evolutionary and adaptive. It has been given recent impetus by the paradoxes that have emerged in successfully applying the previous more limited views. Complex systems behavior, discontinuous change, chaos and order, self-organization, nonlinear system behavior, and adaptive evolving systems are all the present code words characterizing the more recent activities. Such thinking is leading to integrative studies that combine insights and people from developmental biology and genetics, evolutionary biology, physics, economics, ecology, and computer science. It is a view of an actively shifting landscape with self-organization (where the stability of the landscape affects behavior of the variables, and the variables, plus exogenous events, affect the stability of the landscape). It is a view of cross-scale interactions of processes–dubbed panarchy in previous writings (Gunderson et. al. 1995, Holling and Gunderson 2002). It is a view that requires a focus on active policy probes of a shifting domain and a focus on institutional and political flexibility for learning.

Comparing and contrasting these underlying caricatures or worldviews, provides some insight into how we create our wonderlands in order to make prescriptions for action. It is also useful to note how these partial myths are adopted and reinforced and prescribed by a variety of disciplines, as described in the next section, organized around Mad Hatters of various disciplines.

Disciplinarily Mad Hatters

> Alice had been looking over his shoulder with some curiosity. "What a funny watch!" she remarked. "It tells the day of the month, and doesn't tell what o'clock it is!"
>
> "Why should it?" muttered the Hatter. "Does YOUR watch tell you what year it is?"

> “Of course not,” Alice replied very readily, “but that’s because it stays the same year for such a long time together.”
>
> “Which is just the case with MINE,” said the Hatter.
>
> Alice felt dreadfully puzzled. The Hatter’s remark seemed to have no sort of meaning in it, and yet it was certainly English. ”I don’t quite understand you,” she said, as politely as she could.
> ……..L. Carroll

The Mad Hatter utters seemingly nonsensical questions and answers in his dialogues with Alice at the tea party. He reminds me of those of us who are technically or scholarly oriented, the educated skeptics who pay attention to different indicators, have different frames of reference and different interpretations and understandings. As with the Mad Hatter, in attempting to communicate our technical understanding to policymakers or decisionmakers, more often than not, we are politely misunderstood. And all of us are like the Hatter in that we wear our disciplinary hats proudly—whether as ecologist, biologist, political scientist, economist, or any other scholarly categorization. Yet there is a growing sense that these discipline-based organizations of inquiry and understanding are problematic.

Management of global and regional resources is not an ecological problem, nor an economic one, nor a social one. It is a combination of all three. And yet actions to integrate all three inevitably shortchange one or more. Sustainable designs driven by conservation interests ignore the needs for an adaptive form of economic development that emphasizes enterprise and flexibility. Those driven by economic and industrial interests act as if the uncertainty of nature can be replaced with human engineering and management controls, or ignored altogether. Those driven by social interests act as if community development and empowerment of individuals hold the key and there are no limits to the imagination and initiative of local groups. As investments fail, the policies of government, private foundations, international agencies, and nongovernmental organizations flip from emphasizing one kind of myopic solution to another. Over the last three decades, such policies have flipped from large investment schemes, to narrow conservation ones to, at present, equally narrow community development ones.

Each one builds their efforts on theory, although many would deny anything but the most pragmatic and nontheoretical foundations. The conservationists depend on theories of ecology and evolution, the developers on variants of free market models, the community activists on theories of community and social organization. All these theories are correct in the sense of being partially tested and credible representations of one part of reality. The problem is that they are partial. That partiality of concepts leads to the search for theories of change that bridge disciplines in rich ways.

One such integrated theory is Holling’s (1992) adaptive cycle. The heuristic combines ecological theories of succession and ecosystem development with other concepts of stability and resilience. It is a rich framework to indicate how natural capital and connectivity of systems increase slowly over time. But those properties lead to an increasing vulnerability and inevitable periods of destruction and reorganization. Authors have used this framework to explain co-evolution of resources and management through time (Light et al. 1995), business and organizational dynamics (Westley 1995), and political systems (Holling and Sanderson 1996).

The above excerpt from the tea party, in which Alice and the Mad Hatter discuss differences in their watches, also suggests to me that one of the key challenges that resource managers face is overcoming obstacles of scale. Those obstacles are both theoretical and practical. How managers attempt to analyze and learn from their actions are both related to issues of scale. Most models and modes of inquiry are scale bound and dependent. Walters (1997) cites the cross-scale problem as a severe obstacle in most assessment/modeling activities. Development of new theories is needed to help address ecosystem and natural resource dynamics across space and time scales. Over the last 40 years, time and space have been separated for analytical purposes. Most field ecologic investigations either freeze space and experiment over time or freeze time and look at spatial patterns (witness the explosion and ubiquity of geographic information system technology in resource management agencies). Perhaps there are practical reasons for this pattern, but it also can be explained in part because of underlying theoretical frameworks. There is a growing sense that this separable-dimension framework results in assessments with different outputs, suggesting the need for integration and reconciliation.

Through The Looking Glass and What Alice Found There

> For some minutes Alice stood without speaking, looking out in all directions over the country—and a most curious country it was. There were a number of little brooks running across from side to side, and the ground between was divided up into squares by a number of hedges, that reached from brook to brook.
>
> "I declare it's marked out just like a large chessboard!" Alice said at last. "There ought to be some men moving about somewhere—and so there are!" she added in a tone of delight, and her heart began to beat quick with excitement as she went on. "It's a great game of chess that's being played all over the world—if this is the world at all, you know. Oh, what fun it is!
> ……..L. Carroll

One of the enduring and endearing aspects of the *Alice in Wonderland* stories is that she faces an uncertain world (from the nightmarish to the sublime) with hope and wonder. For some who deal with issues of natural resource management, there is only doubt and gloom. However, I tend to agree with Alice, and I suggest that there is reason to hope. But that hope is founded on developing and creating new ways to think about and manage issues of the environment.

Perhaps it is time to rethink the paradigms or foundations of resource management institutions, and place more emphasis on development of sustaining foundations for dealing with complex resource issues. Learning is a long-term proposition that requires a ballast against short-term politics and objectives. Another shift likely will require a change in the focus of actions away from management by objectives and determination of optimum policies toward new ways to define, understand, and manage these systems in an ever-changing world. That focus should not be solely on variables of the moment (water levels, population numbers) and their correlative rates, but rather on more enduring system properties such as resilience, adaptive capacity, and renewal capability. Indirectly, these system properties have been explored in large complex ecosystems such as the Grand Canyon (Walters 1997), the Columbia River basin (Volkmann and McConnaha 1993), and the Everglades (Gunderson 1999). A resilience or adaptive capacity framework involves both the human components of the system (operations, rules, policies, and laws) and the biophysical components of the landscape and its ecosystems. The shift of focus to a learning basis is likely to require flexible linkages with a broader set of actors, or network. Another way of saying this bluntly is, until management institutions are able and willing to embrace uncertainty and systematically learn from their actions and respond to that learning, adaptive management will not continue in its original context, but rather be redefined in a weak context of "flexibility in decisionmaking" (Gunderson 1999).

But what does it take to be hopeful in a world that is perhaps becoming much more unforgiving? As the degree of human impact continues to increase in scale, a key unanswered question is whether the adaptive capacity of both ecologic and social systems can keep pace with this expanding human footprint. Under those conditions, the prescription for facilitating constructive change appears to be:

- Identify and reduce destructive constraints and inhibitions on ecological change, such as perverse subsidies (e.g., sugar farming in the Everglades).
- Protect and preserve the accumulated experience on which change will be based (such as managers in land management agencies with multiple decades of experience).
- Stimulate innovation in a variety of fail-safe experiments that probe possible directions in ways that are low in costs for people's careers and organizations' budgets (such as adaptive policies in the Grand Canyon).
- Encourage new foundations for renewal that build **and sustain** the capacity of people, economies, and nature for dealing with change.

These suggestions are founded on the premise that we must learn our way into an uncertain future. That learning should help guide deliberations toward workable and sustainable futures. Those deliberations will not solve all social or distributional issues, but rather might help frame ways to work through this wonderland of resource management—we don't have the luxury of awakening and realizing that it may have been a dream.

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What Is a Landscape and How Is One Studied?

Virginia H. Dale[1] and Barry R. Noon[2]

Introduction

Because this workshop is entitled "Views From the Ridge," I interpret my task in reviewing contributions to resource management from landscape ecology to be to provide you with the view from Oak Ridge. The Environmental Sciences Division at Oak Ridge National Laboratory (ORNL) was formed in 1955 as a response to the concern of how radiation was affecting the environment. The Division's objectives rapidly expanded to include analysis of environmental effects of all aspects of energy use. This topic clearly encompasses all aspects of environmental sciences, and now our Division houses 96 scientists with degrees from 18 fields of study.

The history of advancements in environmental sciences at ORNL parallels developments in land management and ultimately leads to a landscape perspective. Therefore, I thought it would be useful to highlight those scientific achievements as a precursor to discussing landscapes. Over the years, ORNL scientists have participated in the development of key research areas that formed the basis for landscape ecology (Hagen 1992). Supported by the International Biological Program, the field of systems ecology was created. Systems ecology views ecological interactions from a holistic perspective and seeks to quantify interactions of varied components. Global change research was initiated shortly after views of the Earth from space led to a realization that the ecological system was global. But this view was tainted with clouds of pollution. Recognition that human impacts occur on a global as well as local scale led to remediation science as a way to use the scientific process to learn about ways to remedy pollution problems. Yet this application of ecological science to real-world problems was difficult because of the intricacies of ecological systems. To deal with this complexity, first hierarchy theory (O'Neill et al. 1986) and then risk analysis (Bartell et al. 1994, Suter 1992) arose. However, neither of these advances recognized the spatial relationships inherent to ecological interactions. Landscape ecology has recently come to be a new field of study that explicitly focuses on spatial interactions (Turner 1989, Turner and Gardner 1991).

Need for a Landscape Perspective

From an ecological viewpoint, a landscape is a spatial extent over which ecological processes take place (King 1997). More simply, it refers to a spatially heterogenous area that has a similar geomorphology and disturbance regime (Turner and Gardner 1991).

A landscape perspective is needed to address today's land management problems for several reasons. It is now recognized that the spatial scale of environmental problems is large and that all ecological processes (and management actions) occur in a spatial context and are constrained by spatial location. As an example, Fraser fir (*Abies fraseri* (Pursh) Poir.) are dying in the southern Appalachians as a result of herbivory and population dynamics of the introduced woolly adelgid (*Adelges piceae* Ratzeburg), but the insects' distribution, and thus fir mortality, is influenced by the topographic conditions that restrict the fir to the highest peaks (Dale et al. 1991). Furthermore, ecological systems can be viewed as spatially and temporally hierarchical. That is, processes observed at one level of organization arise from lower level behaviors and are constrained by higher level processes. Therefore, solutions for contemporary environmental problems need to be provided within a spatial context. For example, natural areas that provide essential ecological services are limited in extent, and their contributions must be interpreted within the landscape matrix in which they reside and with the understanding that environmental conditions may change over space as well as time (as with global warming). Thus spatially optimal solutions to land management options should be considered.

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A Landscape Approach to Land Management

The defining attributes of an ecological landscape are structure, composition, function, and change (fig. 1). Structure deals with the physical relationships of landscape elements to each other: their shape, patchiness, juxtaposition, etc. Composition refers to the variety of elements that make up a landscape (e.g., cover types, land forms, etc.). Function indicates the ecological processes that occur on the landscape (e.g., persistence of patches, rates of nutrients and energy flow, erosion, etc.). These attributes lead to the key focus of landscape ecology: estimating the reciprocal relationships between landscape structure, function, and composition and how they might change over time.

Linking landscape ecology to application takes several steps. First, analyses must move beyond a description of the attributes of structure, function, and composition to analyze interactions among these attributes. Second, structure, function, and composition should be considered at multiple spatial scales (see fig. 1). For example, it is critical to know how structure, function, and composition of the landscape are reflected in population or ecosystem features. Finally, knowledge of temporal dynamics of landscape change is essential. Natural disturbance regimes can be characterized by their frequency, spatial extent, intensity, and duration. System resilience has evolved in the context of these disturbances, and thus it is important to compare human-caused disturbance regimes to natural disturbance regimes to determine if human impacts lie within the bounds of system resilience. The concept of historical range of variability has value as a benchmark for human-induced changes. It is important to understand reciprocal relationships between disturbance and landscape pattern (e.g., disturbances both respond to and create landscape pattern).

Key goals of responsible land management are to provide for societal needs without usurping the resources of future human generations and to maintain ecological integrity and thus sustainable ecological systems. The concept of ecological integrity refers to system wholeness, including the presence of appropriate species, populations, and communities as well as the occurrence of processes at appropriate scales (Angermeier and Karr 1994, Karr 1991). To maintain integrity, it is necessary to perpetuate the "characteristic" structure, composition, and processes of ecological systems, preserve those key elements of landscape geometry that facilitate essential processes, retain the productive capabilities of the land, and maintain the evolutionary capabilities of ecological systems. Often resource extraction or use compromises these features of integrity, and thus management actions seek ways to reinstate these features across the landscape.

The Land Use Committee of the Ecological Society of America recommends several guidelines to assist managers in decisions about the use of land (Dale et al. 2000). The guidelines are presented in full awareness that all of these rules of thumb cannot be implemented in every (or even most) situations. These guidelines suggest that, when possible, land managers should:

- Examine impacts of local decisions in a regional context.
- Plan for long-term change and unexpected events.
- Preserve rare landscape elements and associated species.
- Avoid land uses that deplete natural resources.
- Retain large contiguous or connected areas that contain critical habitats.
- Minimize the introduction and spread of nonnative species.
- Avoid or compensate for the effects of development on ecological processes.
- Implement land use and management practices that are compatible with the natural potential of the area.

These guidelines are based on ecological principles such as the idea that the size, shape, and spatial relationships of habitat patches on the landscape affect the structure and function of ecosystems (Dale et al. 2000). This landscape principle has several corollaries:

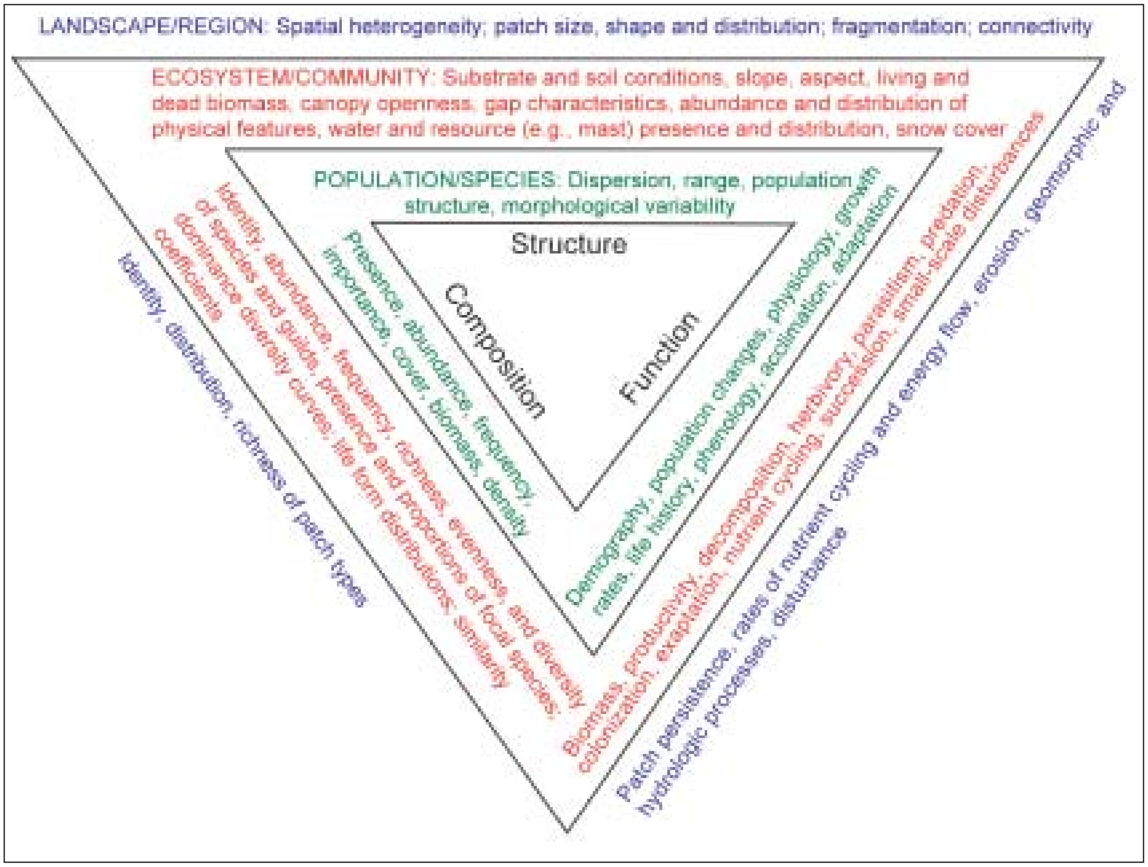

Figure 1—The structural, compositional, and functional components of ecological systems as viewed at various levels of ecological organization: the landscape, ecosystem, and population (from Dale and Beyeler 2001).

- Landscape elements vary in spatial distribution and quality in time and space.
- The structure and attributes of landscape elements and patches affect movement (flows of matter and energy), which in turn affects spatial distributions.
- The nature of boundaries between patches and matrix elements controls horizontal flows across landscapes.
- The spatial context (neighborhood) of a patch affects its properties and dynamics.

Several new insights to management arise from a landscape perspective. The concept of ecological integrity needs further interpretation within the landscape perspective so that it becomes measurable and thus a practical management tool at all scales. Methods are needed to reliably estimate an expected range of natural variation for specific ecological systems (see Parsons et al. 1999).

Improved procedures are needed for selecting ecological indicators to assess the status and trend of ecological systems (allowing interpretation of indicators for large spatial and temporal scales).

Acknowledgments

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How Do We Determine Scale?

Landscapes: The Dilemma of Scale and the Role of Theory

Lee Benda and Daniel Miller[1]

Introduction: The Dilemma of Scale

Landscapes fall into a class of objects that fit the adage: "you know it when you see it, but it's hard to define." As one looks from a ridge into a forested valley, words such as ecosystems, interactions, disturbance, and connectivity come readily to mind. But, it has proven to be another matter entirely to scientifically define a landscape as a whole system of interacting parts that can be readily integrated into management of natural resources, environmental assessments, watershed restoration, and regulation. This is the dilemma of scale. Landscapes comprise thousands of components and processes that are difficult to characterize at any one time. Furthermore, interactions among landscape components occur over decades to centuries, making it difficult to analyze them over the short duration of research studies. The study of landscapes, therefore, poses a complicated problem.

Major components of riverine habitats depend on the supply, routing, and storage of inorganic and organic materials that originate from terrestrial sources. A stochastic climate exerts a degree of randomness in the supply of sediment and organic debris to channel networks over 10 to 100 years; topography and channel-network geometry impose a spatially determined organization in the routing and storage of those materials. Hence, aquatic and riparian habitats have both **stochastic** and **deterministic origins**. Studies that have incorporated stochastic effects have been referred to as disturbance ecology (Pickett and White 1985), temporal hierarchies (Frissel et al. 1986), pulses (Junk et al. 1989), and landscape dynamics (Benda et al. 1998). Studies focusing on deterministic aspects are described in terms of continuums (Vannote et al. 1980), spatial hierarchies (Frissel et al. 1986), ecotones (Naiman et al. 1988), and classification systems (Montgomery and Buffington 1997, Rosgen 1995). Despite a sustained interest in ecological processes over a range of scales (Naiman and Bilby 1998, Swanson et al. 1988), it has proven difficult to develop general principles on how stochastic and deterministic landscape factors, in combination, govern habitat development. One example of this limitation is the continuing inability to define natural disturbance regimes, including the range of variability in aquatic and riparian environments (Benda et al. 1998, Naiman et al. 1995). In practice, this has often led to a preference for single environmental states and single-value regulatory thresholds by many scientists, managers, and regulators.

The lack of quantitative and predictive theory on landscape-scale processes has created a dependence on case studies that often have focused on unique and detailed aspects of landscapes, and on classification systems that emphasized spatial determinism (i.e., stochastic effects ignored). Moreover, theory absence discourages hypothesis testing and commensurable research efforts (similar things measured in similar ways). These problems in combination increase the perceived difficulty of landscape-scale and environmental problems. In sum, the lack of theory hinders the scientific analysis of landscapes and therefore management planning at the landscape scale.

Role of Theory in the Study of Landscapes

"Theory" refers to an explicit set of rules and parameters that are used to describe observed phenomena in a quantitative manner and that accord with the empirical record (Gell-Mann 1994, Popper 1972). Theories should make testable predictions and hence be in a continual state of evaluation, rejection, and modification (Popper 1972). In the study of landscapes, theories are generally applied at small spatial and temporal scales (i.e., slope stability and sediment transport theories). The term "concept" in the aquatic sciences generally refers to new and innovative ideas, and it is that class of knowledge where the greatest strides have been made in articulating the multivariate attributes of landscapes. Concepts, however, do not make testable predictions in the same way

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theories do because they contain components that are not fully or explicitly defined. Concepts may play a key role in the development of a discipline because they act as verbal precursors to the development of quantifiable and testable theories (Haines-Young and Petch 1986). A third class of knowledge, "classification systems," provides an organizing framework for grouping items into similar categories. Classification is a powerful technique for developing a common vocabulary and for arraying physical and biological properties of certain watershed elements. Typically, classification is a precursor to development of theories and laws (Hempel 1966).

Developing theoretical understanding pertinent to large scales is a critical step in the coordinated and organized study of landscapes. First, landscape-scale theory would encourage the measurements of landscape attributes in similar ways, thereby contributing to a regional pursuit of general principles, similar to theories at smaller scales. This would tend to counter the notion that every place is unique and has to be studied uniquely on its own merits. Second, because landscape study is fundamentally interdisciplinary, theory would encourage and guide how different scientific disciplines would need to converge or merge in studies of various phenomena. Third, theory makes it easier and more defensible to extrapolate findings from one landscape to another, thereby obviating the need for re-creating the wheel at every location. Fourth, theory allows "bridges" to be built among incomplete data (either temporally or spatially), a strategy that could be cast in terms of "hypotheses," but that would allow for more comprehensive understanding. This would make explicit the gaps in data and understanding and would aid in targeting future research priorities. Fifth, general theoretical principles would create a hierarchy of scientific understanding in which case studies of processes or conditions obtained over small spatial and temporal scales would be evaluated in the context of the larger scales that characterize landscapes. These advantages would apply to research in the vegetative, geomorphic, hydrologic, and biotic sciences; in natural resource management; and in restoration and conservation biology.

The Study of Large Numbers of Interacting Landscape Processes

Clues for developing inductive or deductive theories at large scales pertinent to landscapes are found in the scientific disciplines that have already tackled problems involving large numbers of deterministic and stochastic elements. One successful strategy has been to represent the interactions of many small-scale processes by larger scale parameters. For example, application of **analytical mechanics** to the problem of landslide prediction views soil as a "continuum," even though soil is composed of many individual grains. For soil, continuum mechanics represents the multitude of millimeter-scale grain-to-grain interactions by meter-scale parameters such as soil cohesion, bulk density, and soil friction angle. (A similar approach has been applied to problems involving turbulent fluid flow [e.g., fluid mechanics]). Analytical mechanics is most effective when dealing with problems at relatively small spatial and temporal scales, and it runs into difficulty when applied at larger scales. For landsliding, the use of a one-dimensional, infinite-slope model is an example of simplifying the interactions of multiple three-dimensional unit volumes of soil involved with failures.

Statistical mechanics provides another technique for predicting the behavior of exceedingly large numbers of randomly behaving elements. A purely statistical approach can describe the behavior of gases that contain vast numbers of randomly colliding molecules (James Clark Maxwell [1831-1879] and Ludwig Boltzmann [1844-1906]). To calculate the macroenergy state of a gas in response to applied temperature and pressure, molecules are parameterized by probability distributions of energy states. As pointed out by Dooge (1986), however, there are large differences between the statistical mechanical approach that depends on concepts of energy equilibrium and average conditions, and the nonequilibrium and transient conditions manifest in hydrologic and geomorphic processes that are of interest to scientists and resource managers.

In the context of these methods, landscapes contain too many components to be treated strictly deterministically and too few components to be treated purely statistically. Environmental systems that fall between the end members of determinism and stochastism but that exhibit both characteristics have been referred to as "intermediate number systems," or systems of "organized complexity" (Weinberg 1975). This characterization also has been extended to ecological and geomorphological systems (Allen and Starr 1982, Graf 1988). To deal with systems of organized complexity, "systems theory" has been developed (Von Bertalanffy 1968). Application of systems theory typically relies on building comprehensive mathematical models that are used to scale up analytical descriptions of processes at small scales to predict the macrobehavior of a system of such processes over larger space and time scales. This so-called "upwards approach" has been applied to the study of certain hydrological problems (Rodriguez-Iturbe and Valdes 1979, Roth et al. 1989, Smith and Bretherton 1972).

Pursuit of General Landscape Theory

The concept of "organized complexity" is proposed as a framework for unifying random and organized attributes of landscapes that govern the flux, storage, and routing of mass between and within terrestrial and aquatic systems. Randomness refers to behavior that is not predictable in detail (such as climate), but that can be described in probabilistic terms. Organization refers to spatial regularities or patterns in a landscape and can include laws of stream ordering and bifurcation (Horton 1945, Strahler 1952), and systematic variations in network geometry, such as decreasing channel gradient and increasing channel width with increasing drainage area (Leopold et al. 1964).

Pursuit of landscape theory requires landscape-scale parameters. These include temporal distributions of the frequency-magnitude characteristics of climatic, hydrologic, and geomorphic events, and spatial distributions that characterize the attributes of large numbers of landscape elements (Benda et al. 1998). A general landscape theory is proposed that predicts how mixtures of climate, topography, lithology, and vegetation impose overarching constraints on the probability distributions and spatial patterns of sediment and wood flux to streams. Included is how temporal distributions of material fluxes evolve along a channel network owing to asynchronous material supply, network geometry, attrition, spatial scale (drainage area), and transport and storage regimes. The derived long-term probability distributions of material flux and storage indicate the stochastic and deterministic origins of aquatic and riparian landforms. Probability distributions also define the space-time structure of variability or the natural disturbance regime.

The general theory is a work in progress, and hence there is need for testing and refining general principles pertaining to climatic and vegetation disturbances, erosion regimes, sediment routing, and wood recruitment. In addition, new theoretical principles covering riparian vegetation and the formation of aquatic and valley floor habitats are needed. Many of the overarching interactions between stochastic and deterministic landscape factors can be sketched on the back of a napkin. Simulation modeling and field studies are needed to make more quantitative and landscape-specific predictions (Benda and Dunne 1997a, 1997b; Benda and Sias 1998). Refer to *General Landscape Theory of Organized Complexity* (Benda et al. 1999) for a more thorough discussion.

Potential Applications of Landscape Theories:

1. Guide field studies of landscape-scale processes.
2. Provide context for studies conducted at small spatial and temporal scales.
3. Define natural disturbance regimes through probability and frequency distributions.
4. Evaluate environmental change through shifts in distribution form (in time or space).
5. Promote risk assessments that use a probabilistic approach.
6. Base environmental analyses, resource management planning, environmental regulation, watershed restoration, and conservation biology on a theoretical foundation.

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Scale Considerations for Linking Hillslopes to Aquatic Habitats

Robert R. Ziemer[1]

The title of this conference, "Views From the Ridge," suggests a particular scalar view of issues. From the ridge, one obtains a somewhat broad but restricted view of the landscape. Certainly, "Views From Space" would provide a larger spatial overview in which landscape pattern becomes a dominant theme. For an aquatic or riparian theme, "Views From the Valley" would suggest looking upward to the hillslope and ridges, in contrast to looking down from the ridge. Issues concerning appropriate scale have been prevalent in most of the recent landscape assessments, including the Northwest Forest Plan (FEMAT 1993), the PACFISH (1994) strategy, and, most recently, the Forest Service *Roads Analysis* (USDA Forest Service 1999) procedure. In all of these efforts, three struggles were common: (1) issue identification and integration of information across multiple disciplines, (2) appropriate spatial scales, and (3) appropriate temporal scales.

Issue Identification and Integration of Information Across Multiple Disciplines

Several decades ago, some of us thought that it would be a good idea to get a bunch of fishery researchers and watershed researchers together for a joint meeting. The joint meeting lasted about 4 hours until someone voiced the opinion that we had nothing in common to speak about and the meeting broke up into two different rooms: one room for the biologists and another for the physical scientists. Since that time, interdisciplinary work has improved. At least now we occasionally can identify common issues. But still, people continue to struggle with understanding the crosscutting complexity within a common issue. For example, foresters tend to identify forestry issues as centered around trees; hydrologists see forestry issues as related to water quality or quantity; biologists see the same forestry issues as revolving around birds, salamanders, or fish. Seldom are we successful in dealing with the full complexity of the issue across disciplines. Traditional ways of looking at problems are either from the top down, or from the bottom up.

Top Down

The top-down approach (fig. 1) starts with some land use activity, such as logging, grazing, or urbanization. The next step is to identify the onsite changes produced by that activity; that is, how does that land use activity modify the site—soil, vegetation, terrain, slope, and so forth. Then, how are these onsite changes translated into altered watershed products? Primary products of altered watersheds are water, sediment, organics, chemicals, and heat. And finally, how are these products transported away from the site of disturbance to cause some offsite impact? For example, suppose there are logging and associated roads in a particular watershed. These activities compact the soil, modify the vegetation, and alter the topography by making the slope steeper at road cuts and fills. These physical changes can modify runoff timing and volume, wood input to streams, surface erosion, and landslides. The result can produce changes in peak flow, base flow, water temperature, channel condition, and sediment. Society is more concerned about the consequences of these changes offsite: increased flooding, increased sedimentation, fewer salmon, and so forth. By looking at the full set of potential influences of a land-disturbing activity, a broader range of potential concerns can be identified than if we simply focused on our favorite impact.

Bottom Up

Another equally useful approach (fig. 2), which is a common engineering exercise, is to identify some offsite impact and trace the way back up to find the activity that caused that offsite impact. For example, if a bridge was washed out, there could be many potential reasons including increased peak flow, channel erosion, water diversion, battering by debris, and so forth. Identification of the correct process and successive linkages is important in order to be successful in preventing future failures or to identify the guilty party.

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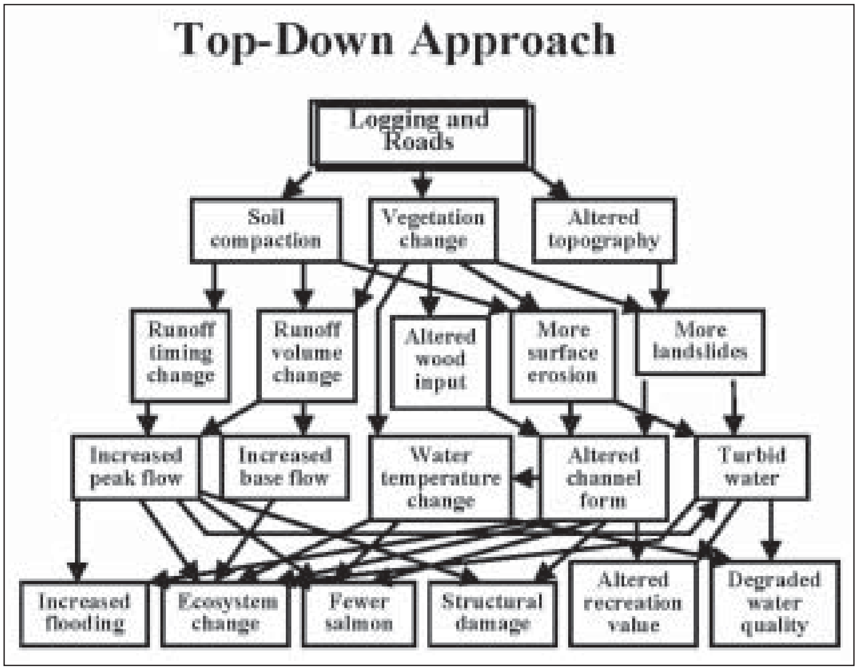

Figure 1—The top-down approach starts with a land-disturbing activity, then describes the onsite changes, the subsequent effects of these changes, and finally the consequences (from Ziemer and Reid 1997).

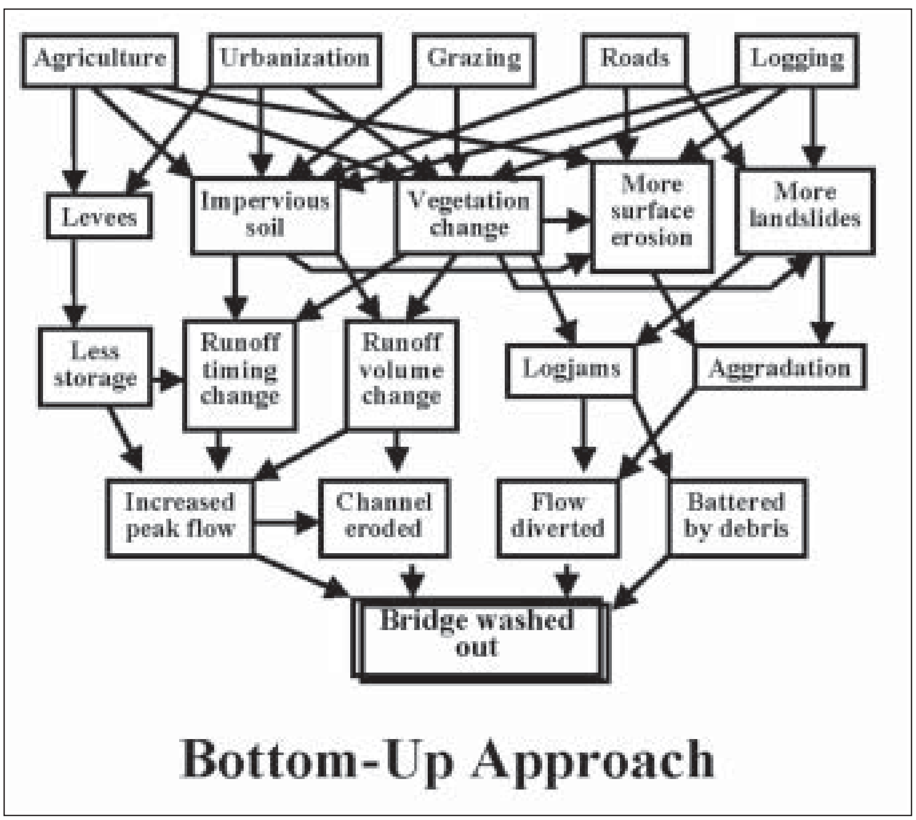

Figure 2—The bottom-up approach starts with an identified consequence (bridge washed out), then describes the important conditions and linkages that could have produced the problem, then the processes that caused the conditions, and finally links to the land-disturbing activities (from Ziemer and Reid 1997).

To be most successful, we should analyze the issues simultaneously from the top down and bottom up by linking the land use activity to potential offsite impacts, and also by linking identified offsite impacts to potential land use activities (fig. 3).

Putting It Together

As an example, let us take "disappearing salmon" as an issue for consideration (fig. 4). If we were to simply focus on the number of salmon at a particular point as the appropriate metric of success, we may develop some programs of salmon restoration that are rather silly when the problem is considered within its broader context. For example, we might try to restore habitat above a dam or a culvert where the fish are unable to reach. Or, perhaps the reason the fish numbers are low is because they were caught downstream. By producing diagrams similar to figure 4, we can begin to visualize and understand the complexity and interactions within the issue of concern. The process of developing the diagram is more important that the final diagram itself. In building the diagram, individuals with different backgrounds and focus can identify where their knowledge contributes to the solution of a single issue. In figure 4, there are three major components potentially affecting salmon: land use, human predation, and ocean conditions. The land use and terrestrial conditions include the traditional issues and linkages: logging, grazing, agriculture, urbanization, dams, and so forth, with their associated effects. The human predation component addresses sport, commercial, and subsistence fishing. The ocean conditions influence a major portion of the salmon's life cycle.

The traditional view of the problem (fig. 5) is to ignore all of this complexity and other influences and focus on the parts that we particularly care about. We select a land use of interest and evaluate the linkages and pathways between that land use (logging) and the target concern (disappearing salmon). Commonly, we further narrow the scope to a specific component, for example, to woody debris. We want to demonstrate that a change in woody debris has some effect on disappearing salmon. So this becomes our top-down approach. We only think about how woody debris is affecting the salmon and we ignore all of the other influences.

It is common to find that an agency only considers those components for which they are directly responsible and ignores the potential effects of other land uses. For example, a forestry agency becomes only concerned with the effects of forest land management on salmon, while the influence

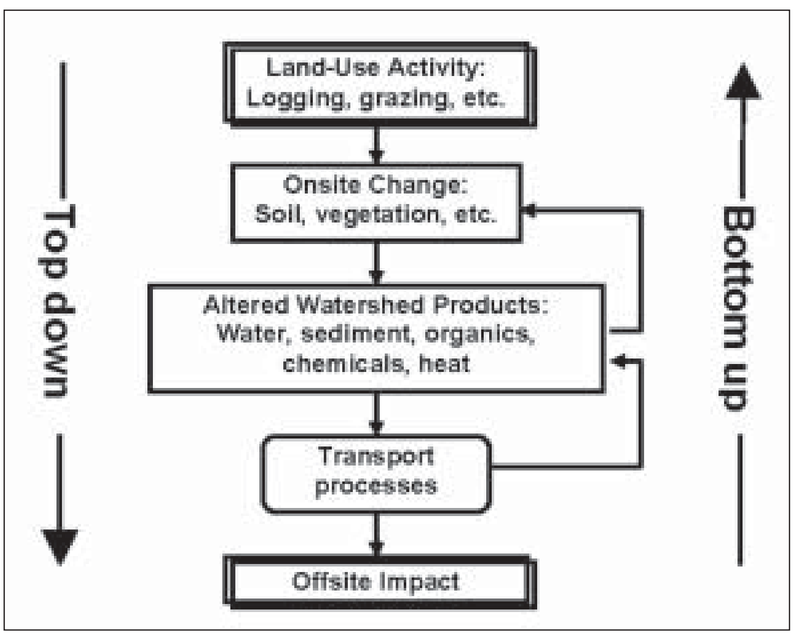

Figure 3—The top-down and bottom-up approaches can be merged into a single-analysis approach by linking the land use activity to potential offsite impacts, and also by linking identified offsite impacts to potential land-use activities.

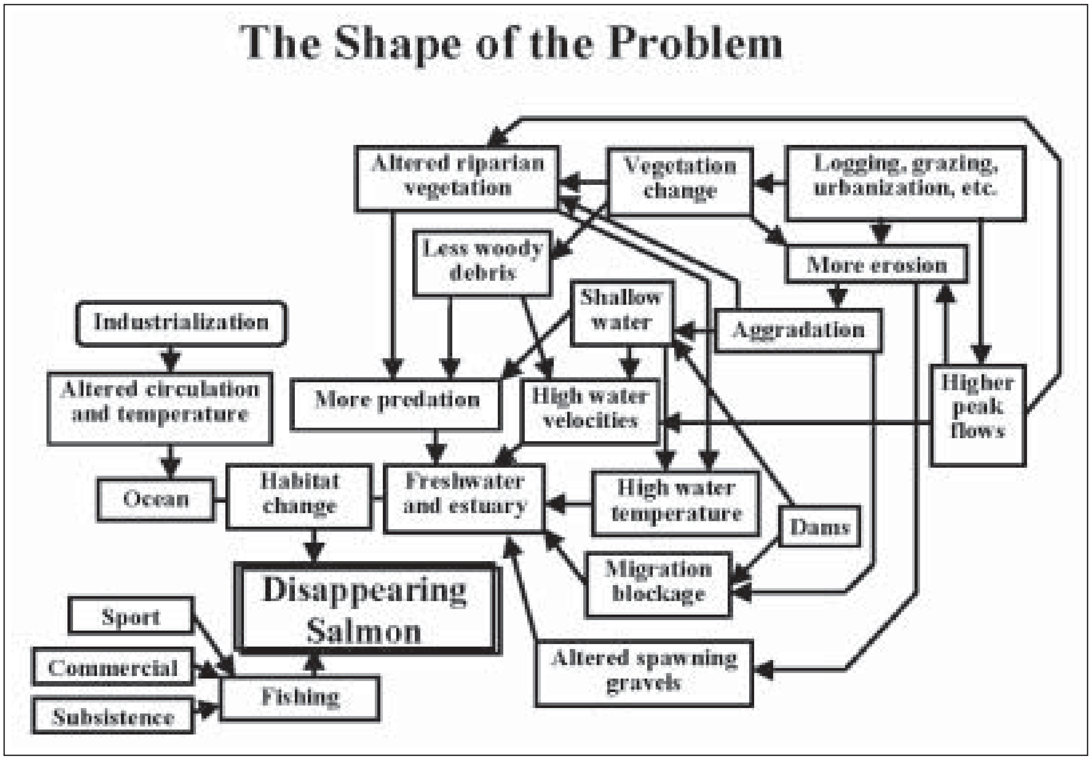

Figure 4—A generalized diagram of some possible important interactions affecting "disappearing salmon" (from Ziemer and Reid 1997).

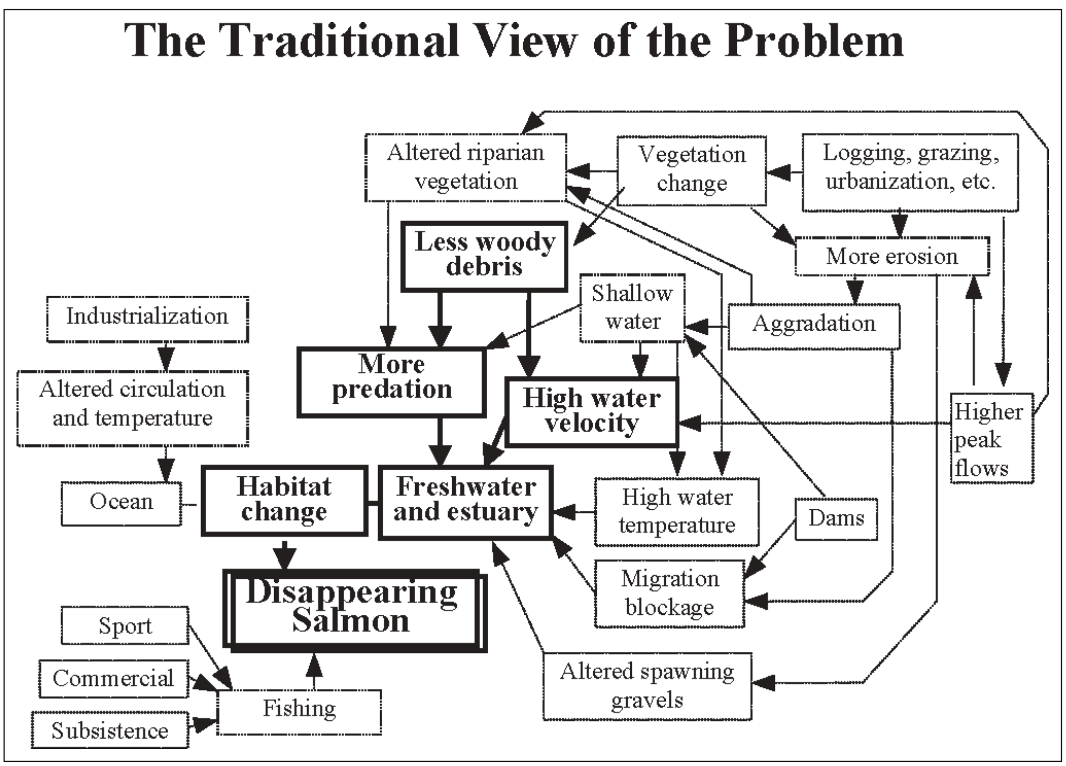

Figure 5—Example of a typical shortcut that ignores many of the important components in the generalized diagram to link a particular component to "disappearing salmon" (from Ziemer and Reid 1997).

of agriculture, urbanization, dams, fishing, and so forth are ignored because the forestry agency is only authorized to regulate logging or manage timberland. This focus is appropriate at a later time when the agency decides upon a program of action. Unfortunately, such a myopic view often misses the context of the agency's program within the larger issue and can lead to uneven regulation or to ineffective management actions.

The end point of problem simplification is to select some index that directly links the activity to the target issue without regard to other influences (fig. 6). For example, a group working to restore salmon runs in the South Fork Trinity River in northwestern California assumed that their favorite variable, changes in the volume of large pools in the mainstem river, was related to the number of returning salmon. The group decided to measure annual changes in the volume of these large pools and then to correlate these annual pool volume changes to logging and road building, which were assumed to produce decreased pool volume, and to the amount of future watershed rehabilitation, which was assumed to result in increased pool volume. In other words, pool volume was the index that was to tie changes in land use to fish. None of the other components or influences upon fish numbers were to be evaluated or considered. The problem was that the group had no information about what was happening to fish downstream and no independent indication that there was any relation between fish numbers and pool volume, let alone between land use and pool volume.

Spatial Scale

Individuals who design projects, such as timber sales, roads, grazing permits, recreation facilities, and so forth, are quite accustomed to and comfortable in dealing with the project or subwatershed scale (fig. 7) that ranges from 10 to a few thousand acres. Project designers are less accustomed to evaluating the context of that project within larger scales. The appropriate size of that larger scale depends strongly on the issue being considered. If, for example, there is a concern about the effect of a project on the drinking water supply for a small community, evaluating the subwatershed directly above the water supply intake is the appropriate geography and scale. Areas beyond that direct influence are not relevant to the problem. If, however, we are dealing with the effect of a project on anadromous fish, then we are dealing with a much different geographical and spatial arena. For each of the boxes and linkages in the disappearing salmon diagram (fig. 4), there are sets of scales that are appropriate to that box. For the fish population, the scales range from the individual stream reach to the Pacific Northwest, including the ocean. Salmon stocks from the Columbia River may compete in the ocean for food and resources with salmon from northwestern California. Anything that changes the competitive advantage of one stock is important to consider. Further, there may be migratory wandering of fish from one river system to another. A depleted stock from one river may result in success of stocks from another river because of reduced competition, or vice versa. It is important to recognize such external forces that are operating at the large scale outside of the immediate frame of reference. Similarly, within a given river system, it is not possible to evaluate the value of improving fish habitat quality at the small watershed scale without some understanding of how habitat along the migratory route influences the population. In the extreme example, improving salmon habitat above a migration barrier will have no effect, because the fish will never be able to use that habitat.

The appropriate scale or geography depends on the issue to be addressed. Some issues remain fixed in one location (trees, soil fertility), whereas others are mobile (animals, water, sediment). Products associated with aquatic issues (water, heat, chemicals, wood, sediment) tend to move downslope or downstream and are constrained within defined topographic boundaries. Fish move upstream and downstream, so for them, watershed boundaries are useful geographic limits. Terrestrial animals (deer, birds) are not constrained by watershed boundaries, and the watershed concept is not particularly useful. For these animals, movement range is a more useful scale than topographic boundaries.

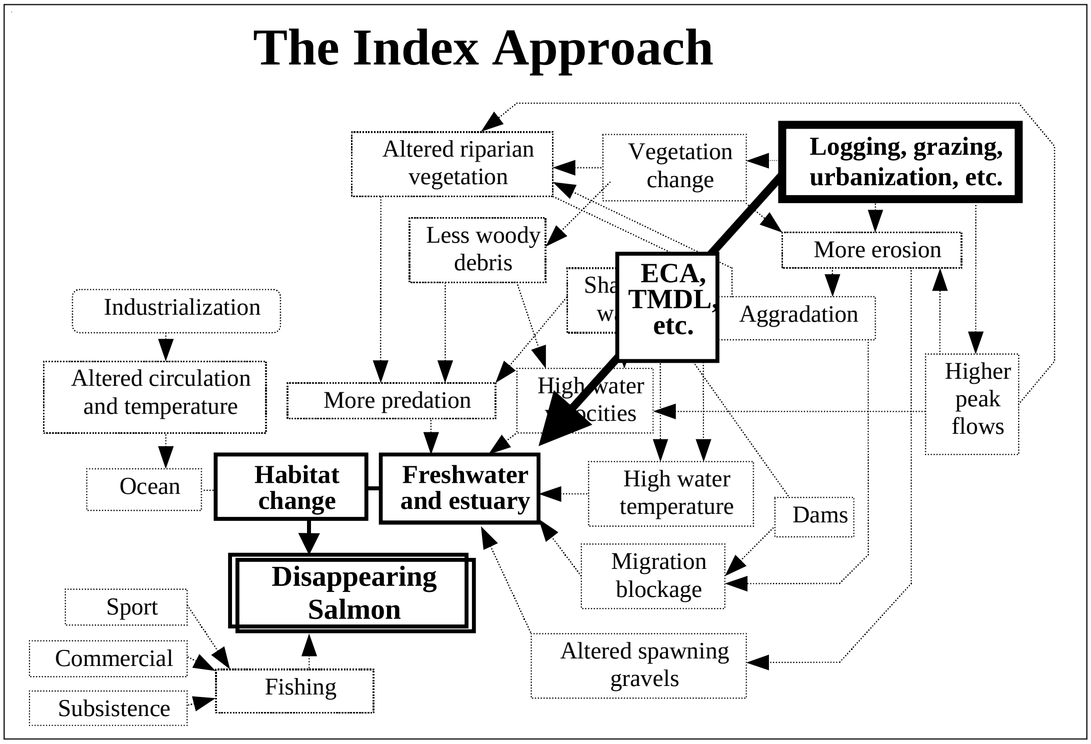

Figure 6—Occasionally, an index is used to link a land-disturbing activity to the target, ignoring all of the complexity and interactions that may also influence the target (from Ziemer and Reid 1997). (ECA = equivalent clearcut area, TMDL = total maximum daily load.)

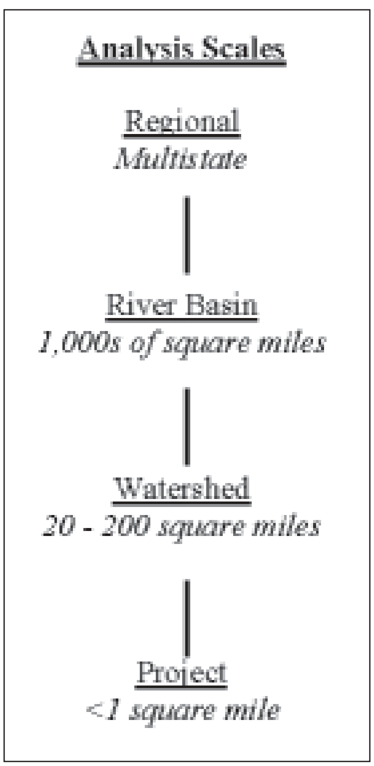

Figure 7—A hierarchy of spatial scales.

A survey of any geographic area will result in a high variance for most parameters. For example, consider a hypothetical survey of 30 streams to evaluate the risk of mortality of some species of fish (fig. 8). Some streams have good habitat and a low risk of mortality resulting from some action, whereas others will have a high risk. The level of "acceptable" risk has two components, biological and social. If the species is abundant, it may be biologically and socially acceptable to adopt a level of regulation that would overprotect some streams and underprotect others. As the species becomes rarer, a higher level of regulation may be appropriate, depending on the consequences of making a judgment error. The problem with regulations that produce or require a generic "designer stream" is that stream systems are dynamic and may require a wide range of evolving habitat conditions to be productive. The stream systems described by Reeves (this volume) require a substantial amount of perturbation and resulting productivity changes over time. Designing for the perceived "ideal" condition in all places all of the time may lead to a poor stream condition in the future. Further, a poor condition today may contain exactly the components needed for the best habitat in the future.

Temporal Scale

It is well known that "significant" hydrologic or meteorologic events occur rarely, and the temporal distribution of these events is not uniform. This presents a problem because most monitoring activities represent only a short snapshot of the temporal distribution of events. If the long-term distribution was uniform and well behaved, the snapshot may be an adequate representation of the expected population of future events. However, if the events are not uniformly distributed (fig. 9), then any short period of monitoring can produce flawed information. For example, assume habitat conditions are monitored on a stream continuously for 75 years, considered by most to be an exceedingly long record. If the monitoring period ran from year 1 to 75 (fig. 9), the conditions represented would be greatly different than if the period was from year 75 to 150. More realistically, most monitoring activities are much shorter than 75 years, often 10 or fewer years. Any 10-year period in figure 9 could find conditions ranging from no severe storms to multiple storms. In other words, the temporal scale needed to adequately represent the significant geomorphic or ecologic drivers is often orders of magnitude longer than our monitoring database.

How does this relate to the level of regulation and risk of mortality? Suppose that the average of the streams depicted in figure 8 had a monitoring record of 30 years (fig. 10). The maximum risk of mortality, and perhaps the appropriate level of regulation, could differ substantially based on which period is monitored: for example, years 1 through 10, years 11 through 20, or the entire 30-year record.

What is the appropriate time scale to consider? The answer depends strongly upon the issue. Different folks or the same folks considering different issues look at the problem differently (table 1). For those in the corporate world of profits and losses, a quarter (of a year) is an important scale. Corporate well-being 150 years from now is often not an important consideration to the board of directors. Politicians like to see programs that they sponsor put into effect and have some result during their time in office. For politicians, the election cycle (2, 4, or 6 years) is an important time scale. The length of a human life is an important time scale for people, and sometimes planning includes several generations, that is, planning cycles ranging from 10 to perhaps 100 years. For most people, something that happened 20 years ago was a long time in the past. With some exceptions, such as planning for infrequent but catastrophic events such as earthquakes and floods, something that happens once every 20 years or so is beyond the immediate concern of most people. However, a 20-year time scale is extremely long for an insect species having several life cycles per year, or extremely short for a redwood or bristlecone pine having a life cycle of 1,000 years or longer. An individual storm becomes very important for the domestic water user who turns on the water tap and finds the water to be turbid. Geomorphic events that shape the stream channel may occur only once a decade, century, or millennium.

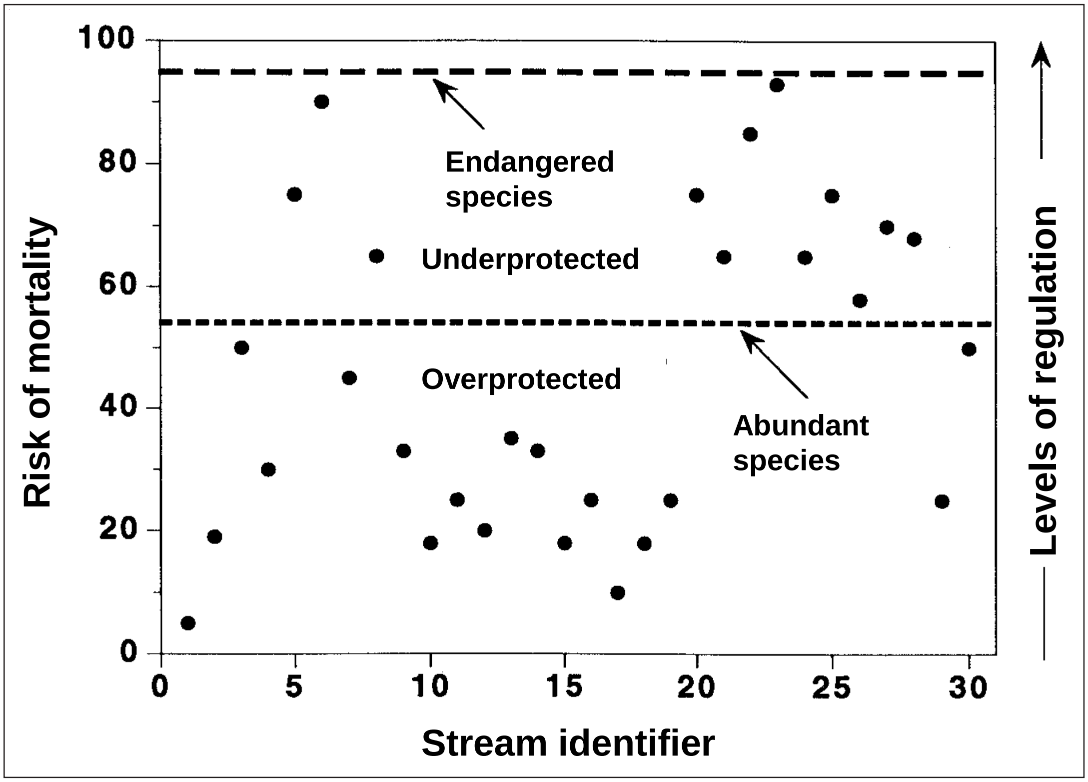

Figure 8—Hypothetical survey of streams for risk of fish mortality and the level of regulation needed to protect fish at two levels of abundance (from Ziemer 1994).

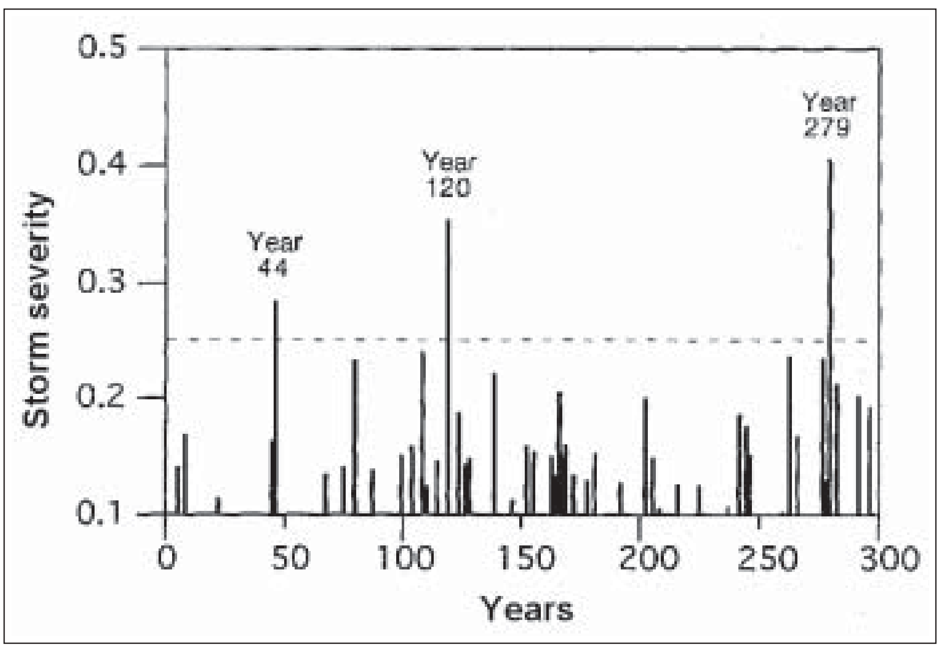

Figure 9—Distribution and magnitude of severe storms during a single 300-year simulation (from Ziemer 1991).

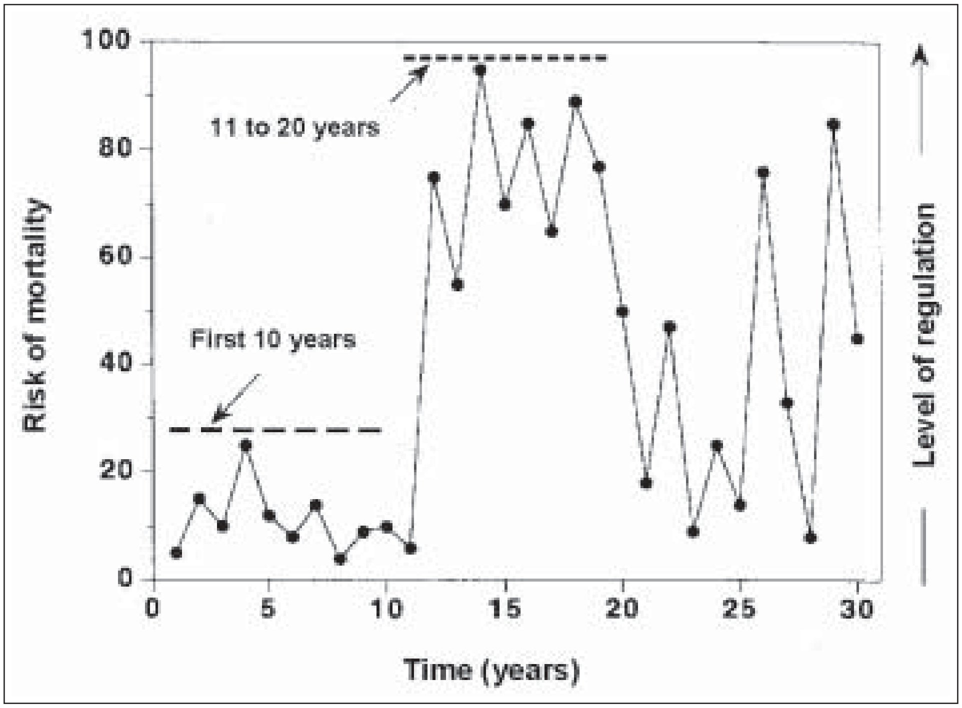

Figure 10—Hypothetical risk of fish mortality based on monitoring streams for different periods of time and the effect of cycles or unusual events on the perceived level of regulation needed to protect fish (from Ziemer 1994).

Table 1—Appropriate time scales

Entity	Period	Years
Corporations	Quarterly profits and losses	0.25
Politicians	Election cycles	2, 4, or 6
Humans	Memory of significant events	1 to 20
Humans	Lifespan	50 to 100
Insects	Life cycle	0.2 to 1
Anadromous fish	Life cycle	2 to 4
Humans	Life cycle	50 to 100
Trees	Life cycle	100 to 1,500
Domestic water user	Individual storm	0.1 to 5
Channel adjustments	Large storm	1 to 1,000

Finally, how one views the world depends strongly on conceptual models about how things operate. For example, our belief about how the level of watershed disturbance is related to salmon habitat (fig. 11) has a strong influence on land management and restoration strategies. The initial assumption for both curves a and b is that the best habitat represents that area having the least watershed disturbance. In one model (fig. 11, curve a), a watershed can be increasingly disturbed with little effect on habitat quality until a threshold is reached, beyond which there is a precipitous decline in habitat quality. The management objective would be to allow disturbance activities to continue until just before the point is reached where habitat quality begins to drop rapidly. Conversely, curve a suggests that a severely degraded habitat can be restored with a small reduction in the amount of watershed disturbance.

The second model (fig. 11, curve b) suggests that a small amount of disturbance in watersheds having the best habitat can result in a rapid decline in habitat quality. Once the habitat quality is low, additional disturbance has little incremental effect on habitat quality. Conversely, curve b suggests that recovery of habitat quality in heavily disturbed watersheds will require a huge effort before any improvement will result. Many past land management plans followed assumptions of curve a. The Northwest Forest Plan (FEMAT 1993) aquatic conservation strategy follows the assumptions of curve b, that is, to identify and protect those watersheds that have the best remaining habitat (key watersheds), and to concentrate continued harvesting in those areas having the poorest habitat (matrix). It is important to determine which of these models best represents the relationship between watershed disturbance and habitat quality.

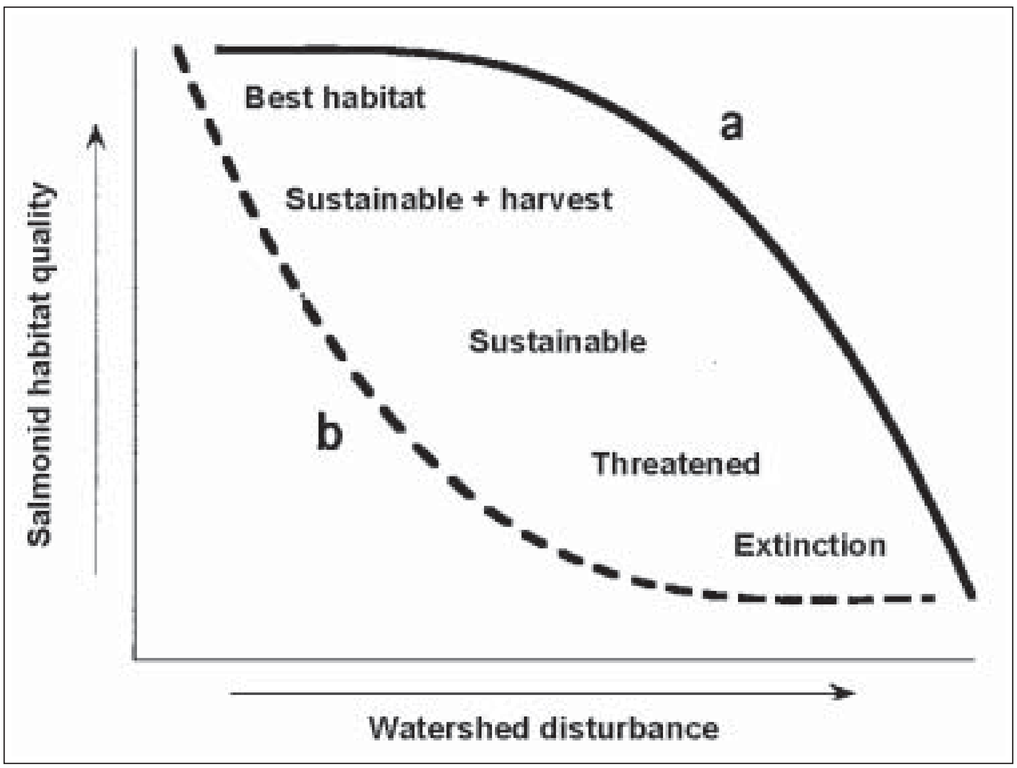

Figure 11—Two conceptual models of the relation between watershed disturbance and salmonid habitat: (a) habitat quality is not degraded until substantial watershed disturbance is reached; (b) habitat quality is degraded most quickly during initial stages of watershed disturbance (from Ziemer 1997).

Conclusion

Management and policy strategies to sustain a resource depend on physical and biological hypotheses that often are untested. The success or failure of a particular strategy will depend strongly on how the resource actually responds once that strategy is applied. Understanding the response of the resource, in turn, will depend critically on viewing that resource from the appropriate scale in time and space.

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Landscape Assessment in a Multiownership Province

Thomas A. Spies[1]

Controversies about forest sustainability, advances in the sciences of landscape ecology and ecosystem management, and new tools such as geographic information systems (GIS) and remote sensing have led natural resource policymakers, planners, and managers from the stand, to the landscape, and to regional scales. As scientists and managers have expanded to these broader scales, they have typically encountered multiownership landscapes. The management and scientific challenges posed by multiownership landscapes are especially complex. Species and ecosystems do not recognize legal boundaries between ownerships, and the landscape dynamics of individual ownerships are controlled by a complex of economic, social, political, and biophysical forces. The aggregate ecological conditions of landscapes are controlled by the spatial pattern and dynamics of individual owners and ecological interactions among those ownerships. The dominant disturbance regimes in many landscapes are now directly or indirectly controlled by human activities. Consequently, to understand and predict these anthropogenic disturbances, we must also understand their linkages to economics, policy, and sociology. Solutions to problems of conservation policy and practices for multiownership landscapes do not lie in isolated owner-by-owner planning and management. Broader scale approaches are needed. Work in multiownership landscapes also reveals the need for increased integration among ecological and social sciences. The challenges to conducting integrated regional assessments are numerous and frequently not appreciated by scientists who typically have little experience in these types of efforts.

A group of Pacific Northwest Research Station and university scientists is currently involved in a research program that is designed to test and evaluate multiownership issues at province scales. The Coastal Landscape Analysis and Modeling Study (CLAMS) is a large interdisciplinary effort designed to evaluate aggregate effects of different forest policies on the ecological and socioeconomic conditions of the Coast Range province as a whole (Spies et al. 2002; www.fsl.orst.edu/clams). Here, I briefly describe our general approach and present an example of a simulation of changing forest landscape conditions over time. I discuss the potential ecological consequences of the mosaic of different ownership policies and conclude by identifying some of the challenges associated with building integrated regional models.

The goal of CLAMS is to develop and evaluate concepts and tools to help understand patterns and dynamics of ecosystems at province scales and to analyze the aggregate ecological and socioeconomic consequences of forest policies for different owners. Our approach is based on the assumption that by knowing landscape structure and dynamics of vegetation we can project consequences of different forest policies for biological and social responses. The major steps in our approach are:

1. Build high-resolution spatial models (grain size of 0.1 to 10 ha) of current biophysical conditions (e.g., vegetation, ownership patterns, topography, streams) across all owners by using Landsat satellite imagery, forest inventory plots, and GIS layers.
2. Conduct surveys and interviews of forest landowners to determine their expected management intentions (e.g., rotation ages, thinning regimes, riparian management intensity) under current policies and to develop spatial land use change models based on retrospective studies.
3. Project expected successional changes in forest structure and composition under different management regimes by using stand dynamics models.
4. Build a landscape change simulation system based on forest management intentions and forest stand models to project potential landscape structure for 100 to 200 years.

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5. Develop biophysical response models for habitat quality for selected terrestrial and aquatic vertebrate species, viability of selected vertebrates species, coarse-filter measures of community and landscape conditions, historical range of natural variation of forest successional stages, and landslide and debris flow potential.
6. Develop socioeconomic response models for measures of employment and income by economic sector, timber value and production, recreational opportunities, and contingent value of biological diversity to the public.
7. Estimate potential ecological and socioeconomic consequences of current forest policies by using the landscape simulator and various response models.
8. Evaluate, test, and revise overall simulator system and submodels.
9. Provide policymakers, landowners, and the public with results of spatial projections of consequences and interact with those groups of people to help inform debate and facilitate collaborative learning.

At this point in the project we are simulating only forest management-related disturbances (e.g., clearcutting, partial cutting, thinning) and landslide and debris flow disturbances. We focus on these because they are among the most frequent in the region, potentially have large impact on measures of biological diversity, and are of great interest in current policy debates. We are not simulating stochastic disturbances such as wildfire, wind, insects, and disease. Studies in the region indicate that wildfire occurs infrequently (150 to 400 years) and its spatial pattern is only weakly controlled by topography, especially for large fire events (Impara 1997). Smaller wind and pathogen disturbances are quite frequent, but they are difficult to predict and typically occur at patch sizes below our level of spatial resolution for this provincial study. Climate change is another process that we do have in the current model. These other ecological processes could be incorporated into future modeling efforts, either directly in the simulation model or as scenarios (e.g., effects of a large fire) for comparative analysis. These processes could have profound implications to management. For example, a large, rare fire event could influence ecological and socioeconomic systems for decades and centuries. Relatively fine-scale processes such as disease or landslides could affect biophysical potential across large areas. We do not mean to imply that these other processes are not important but our initial interest is in isolating the effects of management actions. The model should be viewed not as a predictive tool but rather as a computer-based experiment to provide insights into the relative effects of different forest policies.

We developed a prototype of our landscape simulator for the Coast Range province and ran it for a 100-year scenario under current policies (fig. 1). Patterns of current forest condition are nonuniformly distributed across ownerships. Current vegetation patterns in the province are characterized by a predominance of early and mid-sized conifer forests. Forests dominated by trees of the largest size classes (large and very large conifers) are rare and restricted primarily to public lands. Broadleaf forests are less common than coniferous forests and tend to be concentrated in riparian areas. Old-growth forest condition (approximately equivalent to the very large conifer class) is currently a small percentage of the total area, and what is remaining is concentrated on Bureau of Land Management (BLM) and Forest Service lands in the southwestern portion of the province. Little old growth occurs on private land, but some small remnant patches do occur and form the basis of Habitat Conservation Plans for the northern spotted owl (*Strix occidentalis caurina*). Conversely, open (pasturelands, meadows, agricultural lands, and recent clearcuts) and early-successional stages of forest (typically forests less than 15 to 20 years old) occupy almost 40 percent of the province and are concentrated on private lands.

By 50 years into the simulation of future conditions, the pattern of vegetation classes has changed dramatically. Amounts of large-diameter classes have increased, especially on federal lands, and the spatial pattern of vegetation has begun to resemble the underlying ownership pattern. Young plantations (10 to 30 years old) on federal lands have matured and are beginning to blend into the matrix of large conifer size classes. On private lands, intensive forest management

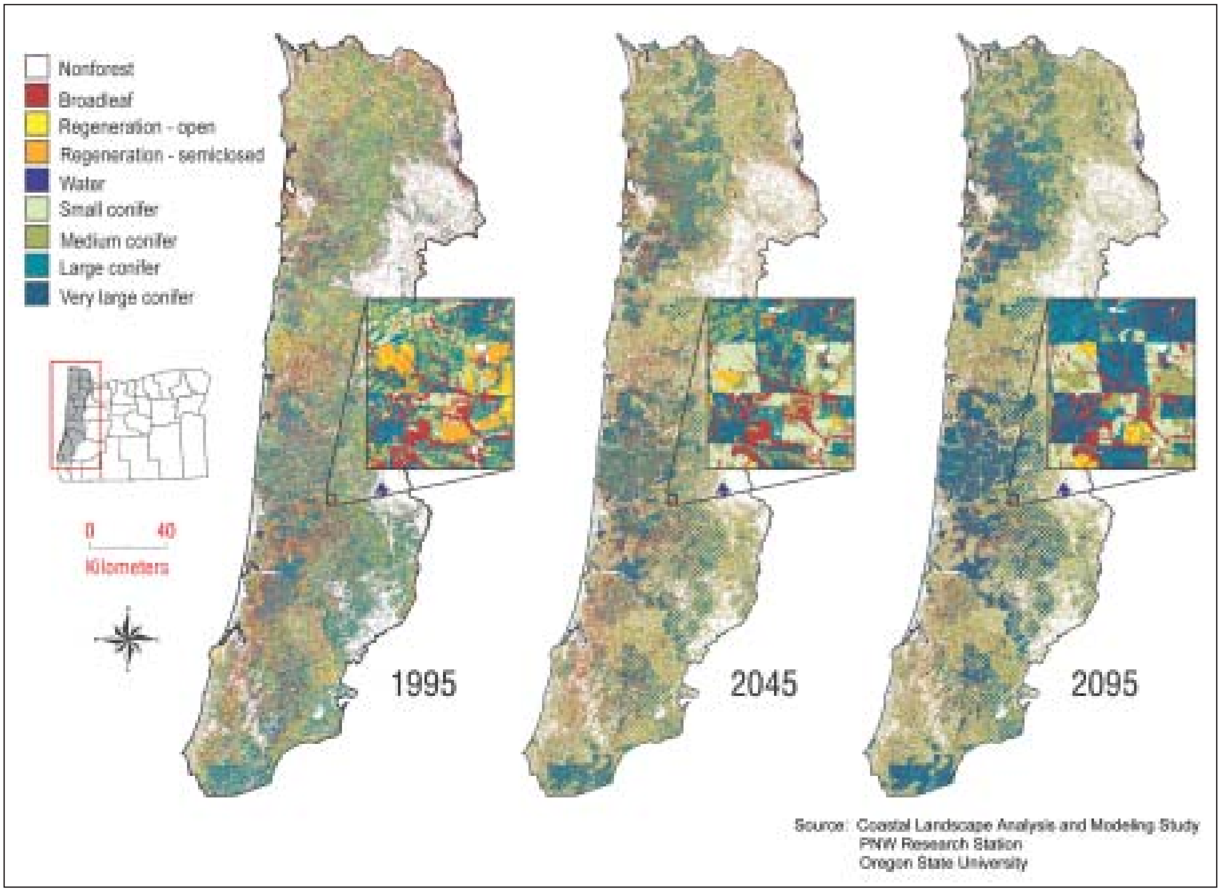

Figure 1—Current conditions (as of 1995) and simulated changes in forest types of the Coast Range at 50 and 100 years into the future under current policies.

(40- to 50-year rotations) keep these landscapes cycling between early successional stages and harvest-age timber plantations. By 100 years, the contrasting patterns of vegetation across ownerships are even stronger.

Although total amounts of late-successional forest have increased dramatically in the Coast Range in this simulation, the spatial pattern of these forests creates considerable potential edge effects and spatial pattern interactions, especially on BLM checkerboard lands. The simulations suggest that large watersheds of the Coast Range will develop into a mosaic of very different landscape types based on the amount and spatial pattern of forest conditions. These landscapes range from watersheds dominated by late-succesional forest to watersheds dominated by early-successional and mature-forest plantations. Between these extremes is a wide range of mixtures of successional dominance and dispersed or blocked spatial patterns. Consequently, we hypothesize that a new landscape pattern is emerging in this province in which ownership patterns, management strategies, and boundaries will control patterns of biophysical processes more than in the past. The ecological and socioeconomic consequences of changing diversity and spatial pattern are the primary focus of our ongoing research efforts.

To summarize, we have learned that recently enacted forest policies in the Oregon Coast Range have the potential to create novel landscape patterns of vegetation. We hypothesize that in this dynamic landscape, the combination of complex ownership patterns, contrasting management regimes, and ecological processes create the spatial interactions that could not be predicted based on information from individual ownerships in isolation from each other. Although simple analysis of ownership patterns indicates a strong potential for aggregate effects in this province, more detailed analyses are needed to test the degree and distribution of these effects. The spatial interactions that we expect to have the greatest impact on the ecological systems of this province are the following:

- Imbalances and gaps in seral stage distributions across environmental strata, including subecoregions, watersheds, and topographic positions.
- Gaps in distribution of habitat of relatively wide-ranging species (such as the northern spotted owl or salmonids) whose movement patterns are at similar scales to ownership tracts and management allocations within ownerships.
- Decline in aquatic habitat quality in stream reaches and watersheds as amounts of large wood are lost because of forest and agricultural management practices along streams and upslope in landslide and debris flow areas that are sources of large wood for many streams.

The building of integrated regional models to assess forest policies is a relatively new endeavor, and many scientists have little experience with this type of integrated research, which also may be conducted in an unfamiliar policy and public environment. We have learned much about the process of building integrated regional models to assess ecological and socioeconomic effects. Our lessons learned include:

- **The importance of problem definition and the conceptual model**. Without adequate problem definition and conceptual framework, the process can degenerate into separate studies that may not meet project goals.
- **The importance of involving policymakers and identifying policy questions**. Without incorporating policymakers and specific policy questions at the beginning, the potential relevance of the project will be diminished.
- **The difficulty of developing spatial information about landscapes and regions**. Spatial information about provinces and regions is inadequate and will always be flawed. The challenge is to determine when data quality is good enough to provide a first approximation at large scales.
- **The value of landscape projections**. Spatial projections of possible future landscapes are a powerful way to engage policymakers and stakeholders in joint learning efforts.
- **The challenge of measuring ecological effects**. We lack quantitative measures of ecological response. The challenge is to blend empirical, modeling, and expert judgment approaches to provide working hypotheses for use in model projections and to direct future research.
- **The challenge and importance of scale**. The spatial and temporal scales of ecological, policy, and socioeconomic processes and measures are typically not the same. Continuous attention to scale is needed to ensure that linkages can be made among components.
- **The diversity of ways that integration either happens or not**. Integration across disciplines is central to the effort. Although not all scientists in the team have the time and interest to attend to integration of the project as a whole, one or a few leaders must pay close attention to this process.
- **The challenge of conducting science in public policy and private landowner environment**. Applying landscape ecology to large multiownership areas cannot be done entirely within the walls of a research institution. Scientists must interact with policymakers and stakeholders in new and sometimes uncomfortable ways. These interactions can be time consuming and disruptive to the “normal” process of research. Without them, however, the relevance of the effort can be seriously jeopardized.

These lessons on the process are important for scientists, policymakers, funding agencies, and management agencies. These types of efforts require, above all, patience, leadership, long-term funding, and flexibility to deal with different perspectives and changing goals.

Beyond these challenges and the lessons from the research process, we expect this effort to make significant contributions to policymaking and the science of landscape assessments. We expect that the detailed ecological and spatial structure of the model will help us understand the relative importance of fine-scale management decisions at broad scales and the importance of broad-scale policy decisions at fine scales. We expect to determine the locations in a region that can provide the greatest contribution to biodiversity goals. We expect to learn if a different mix of policies could provide greater overall ecological and socioeconomic values than the current policies. Finally, we expect to discover how much fine-scale information is needed to answer our questions and understand the dynamics of landscapes and ecosystems at broad spatial scales.

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Implications of Scale on Viability Assessments of Terrestrial Wildlife Species

Martin G. Raphael[1]

Introduction

A prudent manager desiring to meet objectives of ecological sustainability and society's economic needs and social desires must consider a variety of scales, both temporal and spatial. This is perhaps an obvious point, but the techniques and operational requirements to manage at multiple scales are not always so obvious. Large-scale assessments and conservation strategies, such as the Northwest Forest Plan and the ongoing Interior Columbia Basin Ecosystem Management Project, illustrate the challenges and frustrations of managing at multiple scales. In particular, meeting the legal requirements for species viability, as embodied in the Endangered Species Act and the National Forest Management Act, has forced a clear and explicit recognition of the need for a broader view and has crystalized the difficulties managers face. In this paper, I introduce some of these challenges and describe recent attempts to meet them.

The viability requirement of the National Forest Management Act illustrates the many facets of species conservation. Viability is defined in the current regulations (36 CFR 219.19) as:

> ...a viable population shall be regarded as one which has the estimated numbers and distribution of reproductive individuals to insure its continued existence in the planning area. In order to insure that viable populations will be maintained, habitat must be provided to support, at least, a minimum number of reproductive individuals and that habitat must be well distributed so that those individuals can interact with others in the planning area.

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Key points in this definition include considerations of **numbers, distribution, interactions** (i.e., among individuals within populations), **habitat**, and **boundary** (i.e., planning area). New draft regulations, as proposed following the report of the Committee of Scientists (Federal Register 2000 65: 67514-67581), define species viability as:

> A species consisting of self-sustaining and interacting populations that are well distributed through the species' range. Self-sustaining populations are those that are sufficiently abundant and have sufficient diversity to display the array of life history strategies and forms to provide for their long-term persistence and adaptability over time.

New considerations introduced in these regulations include **adaptability** (a concept that includes genetic diversity), and **time**.

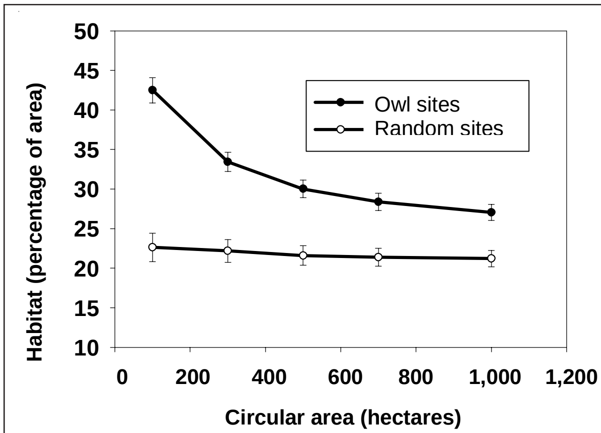
All Scales Count

To evaluate whether management will contribute to or detract from species viability, one must consider a variety of scales, both spatial and temporal. The reason for this is simple: animals respond to their environment at a variety of scales. For example, consider the marbled murrelet (*Brachyrhamphus marmoratus*). This bird nests on large-diameter branches of large-diameter coniferous trees, usually within patches of older forest. At the microsite level, a tree must have a sufficiently large limb to support the bird's nest. At a slightly larger scale, the important elements are the nest tree itself and the structure of the canopy surrounding that tree. A nesting murrelet feeds in coastal waters and makes daily trips to the nest to care for its young. The canopy must allow space for a flight path into the nest. At the same time, cover must be sufficient to protect the nest from potential predators. Therefore, the structure of the nest stand is also important as the size and shape of that stand may influence the abundance of predators and the susceptibility of the nest to predation. Over a broader scale, one must consider the total extent of suitable nesting habitat, as this determines the size of the murrelet population and its overall distribution over a landscape.

As illustrated in this example, several levels of habitat selection exist. The smallest scale is where individual animals obtain resources at any point in time. It is where a nest is located or where a prey item is captured–a specific microsite or habitat element. An intermediate scale is an animal's home range, the geographic area an animal traverses to obtain resources during a specified period. A description of habitat conditions within a home range might include the extent of various cover types, their arrangement and pattern, and the composition of each of the types of cover. A larger scale encompasses the set of conditions that support a population of animals over time. The size of the area to consider is determined by the extent of the population or may be an arbitrary definition covering a specified number of individuals from within a larger population. At an even broader scale, patterns of biodiversity might be described. This scale covers the geographic area needed to support a community of species, each of which is represented by populations. In this case, the area is large enough to contain a variety of cover types and structures, each of sufficient extent to support these populations.

Research on habitat relationships of the northern spotted owl (*Strix occidentalis caurina*) can be used to illustrate the importance of consideration of many scales. As evidenced in figure 1, spotted owls choose nest sites in concentrated patches of nesting habitat. This is suggested by the greater difference between nest sites and random sites at the smallest circle size. As circles around nests grow larger, the differences between amounts of habitat in nest sites and random sites grow smaller. At very large sizes, both nesting circles and random circles would reflect average conditions in the broader landscape. This example shows that smaller scales reveal important biological relationships. In turn, larger scales are necessary to describe population phenomena, so both scales are important in assessing habitat conditions.

Another important scale consideration is the effect of study area boundary on measures of landscape pattern. Using the example in figure 1, note that the smallest circular area contains only one patch of habitat and that the boundary defined by the circle cuts off part of that patch. A measure of patch size is biased because the circle is too small to contain the whole patch. Similarly, measures of edge can be biased because artificial edges are created around the boundary of the study area. This suggests that calculation of measures of landscape pattern should be done on a landscape that is much larger than the average patch size in that landscape, perhaps on the order of 10 to 50 times as large as the average patch size.



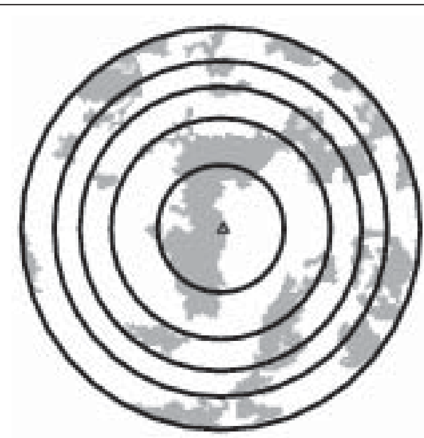


Figure 1—Amount of spotted owl nesting habitat in circular areas of varying size. The figure on the left is a comparison of mean (± standard error) percentage of habitat in a sample of 89 nest sites and 100 randomly located sites, Coast Range, Oregon. The figure on the right is a sample of one site showing habitat (dark) and a nested set of circular areas.

The temporal dimension is also important. Species viability cannot be assessed at a single point in time. At any particular time, a species (or population) exists or it does not. Land managers are generally more interested in the future. A typical question is, If I manage the land in some manner, is it likely the species will persist into the future? Time can be assessed relative to generation time of the species in question. Short-lived species (e.g., most insects or annual plants) experience many generations over a decade; longer lived species may take a century or more for multiple generations to pass. Viability assessments of vertebrates are often considered over hundreds of years.

Species Viability in the Interior Columbia River Basin

The interior Columbia River basin presents another good illustration of the importance of scale in evaluating viability of terrestrial wildlife (fig. 2). In this case, we[2] assessed habitat conditions for a set of individual species at two geographic scales, the subwatershed and the entire basin. At the subwatershed scale, we estimated the total extent of primary habitat within each of about 7,000 subwatersheds that make up the basin. Quality of habitat was adjusted by using models that accounted for more specific habitat elements that might affect populations in that watershed.

[2] Raphael, M.G.; Wisdom, M.J.; Rowland, M.M. [et al.]. 2001. Status and trend of habitats of terrestrial vertebrates in relation to land management in the interior Columbia River basin. In: Forest ecology and management. Elsevier Science B.V. 153(1-3): 63-87.

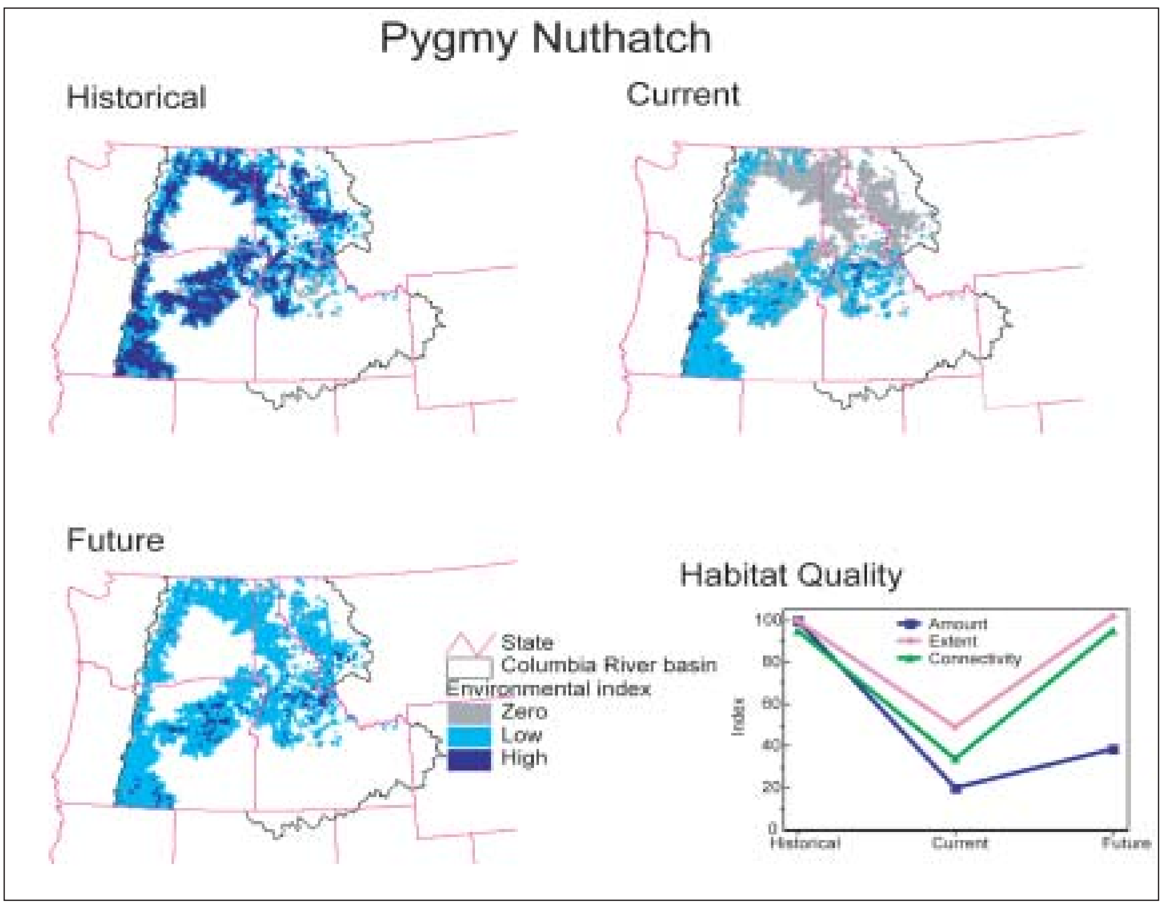


Figure 2—Trend in habitat of the pygmy nuthatch from historical to current to hypothetical future in the interior Columbia River basin.

We then displayed the geographic distribution of habitat quality over a species' range at three periods in time (fig. 2): historically (circa 100 years ago), currently (average conditions over the past decade), and future (100 years into the future under a supplemental draft environmental impact statement alternative). We used three general indices to evaluate, at the broad scale, condition of habitat as it might influence species viability at each period. We summarized the total **amount** of habitat (actually a weighted average of habitat quality relative to historical conditions), percentage of historical range that is occupied (**extent**), and **connectivity** of habitat. By using Bayesian methods and conditional probability tables, these three indices were combined (see footnote 2 for detailed methods) to summarize the likelihood of conditions that would support the species at each time.

As shown in this example, trend in any one subwatershed is not particularly informative in evaluating viability. It is necessary to take a much broader view encompassing the species range to gain such insight. But conditions within each subwatershed are critical for building an aggregate picture of habitat suitability for a given species over an extensive landscape.

Conclusion

Scale is a vitally important consideration in assessing species viability. No one scale is sufficient. We need to consider all scales, from local to regional, and each is important in answering different questions.

Projecting Potential Landscape Dynamics: Issues and Challenges

Ronald P. Neilson[1]

Natural resource science and management seem to have entered the “age of the landscape.” Historically, resources have been studied and managed from a stand, or site, perspective and have generally been approached as single-issue problems. Forests, water, fish, and biodiversity were treated largely as separate topics. The recent shift to a landscape perspective is an explicit recognition that the world is far more complex than can be comprehended from strictly site-based, single-issue studies. Thus, scientists and managers are challenged to address resource issues at multiple scales: site, landscape, regional, national, international, and integrated across multiple resources. Examples of the latter include vegetation and wildlife habitat interactions; upland vegetation dynamics affecting water quantity and quality; climate, vegetation, pest, disease, and fire interactions; ecosystem productivity and biodiversity; and many others. Natural resource management has become so pervasive that it is comparable in scale to most large-scale natural patterns of resource structure and function.

My intent in this discussion is to point out some of the prevailing issues and challenges facing resource managers and scientists alike in predicting or “forecasting” possible trajectories of such complex landscapes. Under the assumption that the climate and land use patterns of the future will be different from the past, I presume that a process-based modeling approach is required, that is, an approach that is robust to changing environmental conditions and that can comfortably incorporate increasing levels of complexity. The discussion reflects my personal views and is not intended to be a complete review of the issues and technologies available.

Natural resource issues occur across a range of spatial and temporal scales. Most processes are small scale, for example leaf physiology or water infiltration. Others are intermediate, or landscape scale, such as metapopulation dynamics or seed dispersal. Few processes are truly large scale. Most large-scale patterns are recognized as “emergent properties,” that is, they arise from small-scale processes and interactions yet reveal coherent large-scale patterns. The distributions of species and ecological zones and the regional patterns of species diversity are examples of emergent properties. Such large-scale emergent properties often are correlated with large-scale climate patterns. However, the regional climate patterns are themselves emergent properties of the small-scale fluid dynamics of the atmosphere, playing out on a rotating sphere and interacting with oceans, continents, mountains, and other surface features, including vegetation.

Correlations between large-scale resource patterns and climate are useful in calling attention to the relationship and point to likely causation. If we could view the climate as a very slowly changing phenomenon, for example, glacial-interglacial cycles, then we could largely ignore mechanisms of interaction between resources and climate and simply focus on the resource processes. However, we now know that the world is heating up and that perhaps half of the current rate of heating is human caused (Trenberth 2001). We cannot say with certainty what the future climate holds, only that we cannot assume the status quo. Thus, we must strive to understand and predict resource interactions and future trajectories from first principles, which take us to the small scale of dynamic processes. Yet, we must acquire predictive capabilities of future resource trajectories over large spatial extents. It is ultimately the regional emergent properties of resources for which we must manage. The challenge of the day, therefore, is to develop predictive capability over very large spatial extents from small-scale processes.

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A Framework for Science and Management

Scientists appear to be converging on a three-scale structure for developing model-based predictive capabilities of resource trajectories and multiresource interactions. These are the site, or stand scale, spanning a few tens of meters; the landscape scale, spanning a few to tens of kilometers; and the regional or continental scale, spanning hundreds to thousands of kilometers. Approaches to these three scales are either top down (empirically based) or bottom up (process based), being distinguished primarily by the resolution of the simulation grid. Stands may be considered as spatially homogeneous at a scale to about 10 meters and may be treated as point simulations, e.g., traditional stand or "gap" models (Shugart and Smith 1996). Stands are also often simulated as spatially explicit with a grid resolution of perhaps 1 meter, but this is less common (Miller and Urban 1999, Peters 2000). Each grid cell contains a full model simulation and may or may not include cell-to-cell interactions. The spatially explicit approach is bottom up; the spatially aggregated approach is top down. The stand or point model can be placed on a grid for spatially explicit simulations of heterogeneous landscapes with a grid resolution of perhaps tens of meters. Regional-scale models are of necessity coarse grid, ranging in grid resolution from about 1 km up to about 50 km or more. Clearly, even the highest resolution regional model must absorb considerable spatial heterogeneity within each grid cell.

Independent models have been developed at all of these scales; however, there is little coherency among those differently scaled models. For example, traditional "gap" models, which simulate succession in a small opening, such as a single-tree blowdown, use empirical curves based on degree-day sums (temperature sums over time) (Botkin et al. 1972), whereas other models might use elaborate physiologically based processes for the same purpose (Running and Hunt 1994). In the extreme, such models can produce opposite responses to external forcing, such as climate change, even though both may be equally well calibrated to current conditions (Loehle and LeBlanc 1996).

One approach to building a verifiably accurate regional-scale model is to take advantage of the top-down and bottom-up approaches across all scales while relying on a core modeling paradigm that carries through all scales. Thus, the core to all of the scales is the site-based model, which must incorporate such things as leaf physiology; competition among life forms for light, water, and nutrients; soil hydrology; and other processes. At each unique scale, scale-specific phenomena likely must be included, but the approach may vary depending on whether it is top down or bottom up. Many forest simulation and management models do not require the physiological, biogeochemical, and hydrological processes (Crookston and Stage 1999). These are empirically based models that cannot accept a changing climate as input. I thus restrict my comments to the process-based approach to ecosystem modeling.

The unique aspect of global ecosystem modeling in comparison to more traditional ecological modeling is that the primary points of interest are the emergent, large-scale spatial patterns and their dynamics. Large-scale biogeographic modeling can be simulated from small-scale processes (leaf to landscape), but calibrated to large-scale biogeographic and hydrologic patterns (Neilson 1995). The challenge is to find the simplest model structure that is sufficient to capture the necessary processes at all the appropriate scales. One may find that a particular mathematical representation of a process works fine in most locations, but needs to be recalibrated at each. Presumably, however, if one is appropriately representing the processes, a single calibration will suffice in all locations. For example, I used large-scale biogeographic and hydrologic patterns as simultaneous constraints to help determine both model structure and calibration (Neilson 1995).

In constructing the Mapped Atmosphere-Plant-Soil System (MAPSS) vegetation distribution model, I coupled the simulation of leaf area index (LAI, the area of leaves per unit area of ground) to the simulation of site hydrology (Neilson 1995). The LAI was used, in part, to define boundaries or ecotones between different vegetation types, such as that between forest and savanna, thus providing the biogeographic constraint at the regional and continental scales. The simulation of LAI was dependent upon the accurate simulation of seasonal soil moisture and its distribution through the soil profile, as transpiration is a function of leaf area, stomatal conductance, and vertical root distribution. The hydrologic module was calibrated against locally observed runoff in contrasting regions across the United States and was initially structured quite simply. However, the simple structure required unique calibrations for each region of the country. I incrementally increased the complexity of the hydrology model until I found the minimum complexity that would accurately simulate runoff in all the diverse regions of the country with a single calibration, and which also accurately simulated the LAI to provide proper mapping of vegetation boundaries. Thus, the model was simultaneously constrained by both vegetation and hydrologic patterns at the large scale of emergent properties, but was based on the simulation of small-scale processes.

A robust framework of science can be constructed by combining the top-down and bottom-up approaches. Each spatial scale can be represented from both perspectives. At the top of the hierarchy, grid cells are sufficiently coarse to simulate wall-to-wall coverage but with uncertainties owing to subcell heterogeneity, because each grid cell is usually treated as being spatially homogeneous. Higher resolution grids can be used; however, the finer scales would only be feasible over smaller spatial extents, that is within a sampling framework over specific watersheds with subplots and so on. Each scale can inform the other; process constraints can be imposed through all levels from a common small-scale theory, and large-scale constraints, such as biogeographic patterns, can be imposed from above. Thus, each level has the ability to peer up or down one level, and the structure can be moved up and down levels for as many levels as are of interest. Yet, the core processes are applied at all spatial scales, thus ensuring that the patterns and sensitivities of the applications at different scales will be fully internally consistent.

Historical management practices can be similarly approached, spatially explicit at a scale of focus, statistical below, and deterministic above. For example, at the national scale, targets might be set for harvest or fuel reduction practices, but their locations are not determined. These targets might be further dissected to specific regions, providing a spatially determined component, but within each domain, the cutting or thinning represents a statistical target and is not spatially determined. This process can continue iteratively, until final operations are spatially determined at the finest scale of interest. This is the inverse of the natural landscape, where the large-scale patterns are emergent from below and constrained from above. Management emerges from the top and is implemented below. However, top-down management also clearly is constrained by the bottom-up spatial resource availability and condition. Nested-scale management modeling can be vertically integrated with the nested-scale ecological modeling. Some of the issues and challenges in constructing the ecological side of this dual hierarchy are addressed below.

Subcell Heterogeneity: Representing the Landscape in Coarse Grids

Much of the challenge of large-scale resource management revolves around the opposing concepts of spatial heterogeneity and homogeneity. For example, as one moves from wet to dry along an aridity gradient, the density of a forest will thin to a point where a grassy understory just begins to be supportable because of enhanced understory light. This is an unstable threshold condition because new processes suddenly enter the system forcing it away from the point of transition as follows. Introduction of an understory entrains positive feedbacks through competition for water, which further thins the canopy overstory. Additional feedbacks through fire can thin the overstory even more, allowing yet more grass and more fire until equilibrium is reached. Thus, the system undergoes a transition from a spatially homogeneous entity to a heterogeneous one. Along this hypothetical aridity gradient, with no topographic complexity, there is an endogenous shift from a homogeneous system (forest) at the wet end to a heterogeneous system (savanna) with increasing aridity and back to a homogeneous system (grassland) with further increases in aridity. The system has also gone through scale transitions, from coarse-scale forest, to fine-scale tree-grass patches, to coarse-scale grassland. Transitions between these physiognomic shifts in heterogeneity are generally termed ecotones and occur at the point of finest scale interfingering pattern between the adjacent homogeneous types.

If we interject topographic complexity to the above moisture gradient, the spatial disposition of ecotones both horizontally and with elevation can become quite complex along both elevational and horizontal temperature and moisture gradients. A transect along the west slope of the Rocky Mountains from southern Idaho to the Mexico border illustrates the complex shifts in elevational ecotones along latitudinal temperature and moisture gradients (Neilson 2003). Winter precipitation decreases from north to south, but summer precipitation increases from north to south in the form of the Arizona monsoon. In combination, the winter temperature and summer moisture gradients create a latitudinal "wedge" of ecotones, upper elevational ecotones increasing with decreasing latitude and lower elevational ecotones decreasing with decreasing latitude. In the southern part of the transect, the wide elevational separation of ecotones creates the classic ecosystem zonation patterns described by Whittaker and Niering (1965) on the Santa Catalina Mountains, Arizona, and earlier by Merriam (1890) on the San Francisco Mountains, Arizona. At the northern part of the transect, however, the elevational ecotones converge, creating a tremendous amount of spatial diversity across microhabitats within comparatively small landscapes. The result is a spatial pattern of complexity through the region that contains both vertical and horizontal gradients of diversity. Peet (1978) described a similar gradient along the east slope of the Rocky Mountains.

It is well recognized that diversity tends to increase at ecotones as the dominant organisms from neighboring domains intermingle into complex combinations (Hansen et al. 1992). Trees and grass, for example, interdigitate at the prairie-forest ecotone, enhancing diversity. The same type of interdigitation and spatial diversity gradients occur at elevational ecotones at the southern end of the Rocky Mountain transect, for example in the Santa Catalina Mountains. At the northern end of the transect, however, with the spatial convergence of ecotones, the different vegetation zones sort out on unique topographic slopes, aspects, and soils, compressing the interdigitation of vegetation from the macroscale to the microscale and creating a wholly new elevational zonation pattern.

Thus, attempts to understand the patterns of alpha, beta, and gamma diversity (local, gradient, and regional) at, for example, only one end of the Rocky Mountain transect, would be only partially revealing and would provide little general understanding of the landscape patterns. The empirical analysis that led to the description of this wedge of ecotones was based on a set of nested-scale experimental seedling transplants along environmental gradients at scales of meters (shrub to intershrub), tens of meters (landscape unique geomorphic positions), hundreds of meters (elevation), and hundreds of kilometers (regional) (Neilson and Wullstein 1983). Yet, simulations at the relatively coarse scale of 10-km resolution (Neilson 1995) were able to elicit the same regional gradients in ecotones, providing inferences to spatial patterns and processes at much smaller than grid-cell resolution.

Such convergence of ecotones may tend to occur where steep airmass gradients converge. I propose that these "nodes" of airmass convergence drive a rescaling of ecological gradients, which is most apparent at the landscape scale. At a distance from these nodes, homogeneous vegetation occurs in large patches, but near the nodes, smaller patches of vegetation intermix on microsites dictated by topography and soil (Neilson et al. 1992). But, perhaps most interesting, is the possibility of inferring landscape-scale patterns from the coarse-scale patterns simulated by the models. Such top-down inference of landscape-scale pattern must, of course, be validated with direct simulation of spatially explicit landscape patterns across regional gradients.

Much of the art in landscape simulation arises in the challenge to validate innovative top-down modeling techniques with direct, bottom-up simulations and ground- or satellite-based data. The question becomes one of how to represent and simulate subcell patterns and dynamics accurately, but without having to do the direct simulation at all locations. A topographically induced mosaic of forests and grasslands would appear as a savanna in a large grid cell. The savanna may provide sufficient accuracy for some issues, but for others, it clearly will not. The spatial heterogeneity can be handled through explicit bottom-up simulation of the complex terrain, or as unique simulations of each patch type as an aggregated homogeneous entity. There are also innovative ways to explicitly recognize heterogeneity in the aboveground components at the landscape scale, while preserving a more homogeneous belowground competitive environment.

Fires and other disturbances in the landscape produce significant problems for large-scale simulations with coarse grids. Fires create a mosaic of uneven-aged patches, with new patches being created as often as each year in some cases. There are numerous differences in the vegetation of an area 1 year after fire and 15 years after fire. In contrast, the differences in vegetation 100 years and 115 years after fire are minimal if the climate and substrate are the same. Thus, one approach is to allow creation of new patches each year and track them individually, but as they become increasingly similar with age, merge them back together. Initially in the course of model development, these patches, in an otherwise homogeneous grid cell, might be noninteracting and only be represented uniquely by their areas and ages. In grid cells with complex terrain, these patches could be maintained on unique soils and with unique climates, but again nonspatially. Eventually, some level of interaction among patches could be implemented, but still without spatially explicit representation within the cell. Spatially explicit simulations on fine-scale grids, coupled with ground and satellite data would assist in the validation of these top-down approaches.

Topographically induced spatial heterogeneity presents additional difficulties when integrating across resources, such as between vegetation and hydrologic processes. Hydrologic processes are strongly coupled to vegetation processes and span scales from local infiltration processes to regional river routing, yet most of the physics occurs at very fine scales. A bottom-up modeling approach will couple the vegetation and hydrologic point-scale processes and also account for the horizontal flows of surface and subsurface water. Thus, accurate representation of riparian zones and stream hydrology is possible. Representation of these interactions in coarse grids also may be possible along the lines described above, but would require direct linkage of subgrid patch types for routing of water between upland and lowland parcels.

Conclusions

Current modeling approaches for natural resource management often are organized around three different scales: patch, landscape, and regional to global. Most large-scale modelers are attempting to incorporate the important processes that occur at all three scales: patch (competition, gas exchange); landscape (fire, dynamic heterogeneity); and global (emergent, spatial pattern). It will be very important for practitioners working within any one of these three modeling communities to coordinate closely with those working at the other scales. Patch models built around one type of ecosystem or in one region may not be well structured for working in other systems or regions. Consistency of process should be maintained across scales. If models are to be nested or linked across scales, then their processes should be based upon the same theoretical underpinnings, or they may not translate well across scales. An area of research that I believe may have some potential, but that remains largely untapped, is the possibility of downscaling from regional to landscape patterns by using coarse-scale information, as in the relation between spatial ecotone convergence and landscape diversity patterns.

The key points of this discussion serve to emphasize the importance of accurate simulation of ecosystem constraints at all relevant scales. Under a rapidly changing climate and with changing physiology under elevated CO_2, constraints normally assumed to be stationary must now be assumed to be dynamic and must be explicitly simulated. Heterogeneous landscapes are among the most complex, yet globally among the most common types of ecosystems. Accurate simulation of landscape patterns and processes under global change requires attention to organism-level and lower processes within the constraints of biome-level dynamic biogeography. A carefully crafted, hierarchical framework with dual-scale representation at each level can provide the structure for integration among natural resources and between management and natural processes in a rapidly changing environment.

English Equivalents

1 meter (m) = 3.28 feet

1 kilometer (km) = 0.62 miles

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Scaling and Landscape Dynamics in Northern Ecosystems

Marilyn Walker[1]

This manuscript overviews issues of scale in relation to the core research of the USDA Forest Service, Pacific Northwest Research Station (PNW) Boreal Ecology Cooperative Research Unit located in Fairbanks, Alaska. The unit's main research focus is the long-term ecology of boreal forests in Alaska's interior region. Other ongoing and related projects focus on pattern and change in tundra and on effects of silvicultural practices on white spruce (*Picea glauca* (Moench) Voss; the major economically important tree species) regrowth following various cutting and clearing treatments. Alaska's interior region and North Slope have experienced a warming trend over the past two decades that has been unprecedented in the last century (Barber et al. 1998, Hammond and Yarie 1996, Juday et al. 1998, Serreze et al. 2000). Understanding how key patterns and processes scale in time and space is absolutely critical to understanding how this system may respond to changing temperatures.

An alternative title for this paper, "Boreal forest–Tundra with trees?", makes reference to the similarities between tundra vegetation and taiga forest understory. The understory vegetation in flat, low-lying areas in northern boreal forests is remarkably similar in both composition and structure to tussock tundra vegetation (Jorgenson et al. 1999, 2001; Walker et al. 1994). This type is codominated by sedges (*Eriophorum vaginatum* L., *Carex lugens* Holm) and shrubs (*Betula nana* L. or *B. glandulosa* Michx., *Ledum palustre* L. ssp. *decumbens* (Ait.) Hulten or *L. groenlandicum* Oeder, *Salix* L. spp.) and underlain by complete coverage of mosses and lichens (*Sphagnum* L. spp., *Hylocomium splendens* (Hedw.) Schimp. in B.S.G., *Pleurozium schreberi* (Brid.) Mitt.). In the taiga, black spruce (*Picea mariana* (P. Mill.) B.S.P.) is also present in open, sparse stands. There is a gradient between full-scale wetlands with few trees to fully closed forests without permafrost.

The need to explicitly recognize and account for scale in ecosystem studies has become increasingly appreciated in the past two decades. Studies that examine pattern or process in space must consider explicitly the sources of variation that are either secondary or primary to the research. This is not a new idea; it is the foundation of biogeography and classical plant ecology, both of which look at patterns of organisms in space and attempt to determine the causal mechanisms behind those patterns. What has become increasingly recognized is how closely together temporal and spatial patterns are tied in most systems, and also how traditional ecological hierarchies do not map directly to more fundamental hierarchies (Allen and Hoekstra 1992, Allen and Starr 1982, O'Neill et al. 1986). Because all landscapes have some degree of dynamism, the spatial patterns at any point in time are the result of multiple processes operating at multiple time scales (Delcourt et al. 1983). The National Science Foundation's (NSF) Long-Term Ecological Research (LTER) Program addresses the problem of temporal scales directly by focusing research resources at selected sites over periods sufficient for explicit study of decadal-scale pattern (Franklin 1987). The Bonanza Creek and Caribou-Poker Creeks LTER site in the Fairbanks region is one of six LTER sites nationally that are cofunded by NSF and USDA, and is one of two such sites within PNW.

Northern ecosystems represent opportunities to examine natural processes at their limits. By focusing at these limits, we can better understand these processes and their roles in complex situations where many factors are operating simultaneously. What is most distinctive about these systems as a whole is that a single factor, temperature, controls essentially all other processes (Chernov and Matveyeva 1997). Therefore changes in this single factor will affect almost all

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processes and patterns. I examine the interactions between climate, species abundance and distribution, and disturbance regimes along a gradient from the northern limit of plant growth to the most northern forests (fig. 1). This gradient covers key thresholds of biodiversity, including the first introduction of woody-dominated ecosystems in the low arctic to the first dominance of trees in the northern boreal forests. The introduction of new functional types into the system, first shrubs and then trees, has dramatic impacts on temporal and spatial patterns, and on how disturbance and vegetation interact.

Vegetation zonation within the arctic regions has been described by many authors, and various approaches have been used to describe these geobotanical zones (Walker 2000). Although slightly different criteria can be used resulting in different outcomes, within Alaska it is useful to recognize three broad zones defined by summer temperature and dominant plant structural types. Table 1 lists characteristics of the three major arctic zones along with transitional and fully boreal zones. There are multiple processes and characteristics associated and interacting with these structures. Species richness is very tightly correlated with temperature at multiple scales in these systems (Chapin and Danell 2001, Walker 1995, Walker et al. 2001). The decrease in species richness from south to north is mainly due to loss of species rather than turnover in species, so that the most northerly floras represent depauperate versions of the southern ones (that is not wholly true, but it is a reasonable representation). Therefore, the latitudinal similarities among the vegetation and flora increase from south to north, because there is a smaller pool of species available. Until treeline is encountered, the dominant species are the same or closely related throughout the zone; however, the species representing the northern treeline vary throughout the region (Alexandrova 1980).

Because this is such a major gradient in both climate and structure, many other variables are simultaneously changing and correlated along the gradient including available moisture, energy balance and radiative transfer, distribution and depth of permafrost (permanently frozen ground), biomass and production, and others. Changes in vegetation structure and composition along this gradient do not follow a classic life-zone pattern of movement up and down an altitudinal gradient. Instead, trees and shrubs first come into the landscape at midslope positions (fig. 2) (Van Cleve and Viereck 1981). The presence of shallow permafrost results in a sealed hydrologic system and drainage conditions unsuitable for tree growth at lower slope positions. The exception is black spruce, *Picea mariana*, which grows in open stands in permafrosted lowlands or on north-facing slopes.

The introduction of trees into the landscape has an overridingly important influence on the spatial and temporal domains of the systems (fig. 3). The main differences between the two systems are:

1. Insects and herbivores have a more consistent and extensive role in the boreal system.
2. The roles of fire and flooding are out of scale relative to other disturbances in the boreal system, with fire being the more significant.
3. The formation and melting of ice wedges is a significant disturbance in the Arctic, whereas in the current boreal climate, the main effect is surface melting of permafrost (thermokarst), with less recovery. Ice wedge formation is on a scale small enough to be considered insignificant as a landscape-forming process.
4. The current timber harvest regime is quite small relative to other stand-replacing disturbances. However, new technologies and economies in fiber harvest may result in a very different regime in the near future.
5. Patterns of eolian loess distribution in the systems differ because of an interaction with topography, vegetation, and wind regime. Arctic rivers follow broad, often anastomosed pathways with large expanses of barren or nearly barren silt and sand bars. Nearly constant wind redistributes this loess across the landscape, with major influence on patterns of vegetation composition and productivity (Walker and Everett 1991, Walker et al. 1998). The Alaska boreal forest has little wind compared to the Arctic, and although there are active sand and silt bars associated with medium and large rivers, much of what is blown off is effectively trapped by the riparian and flood-plain vegetation.

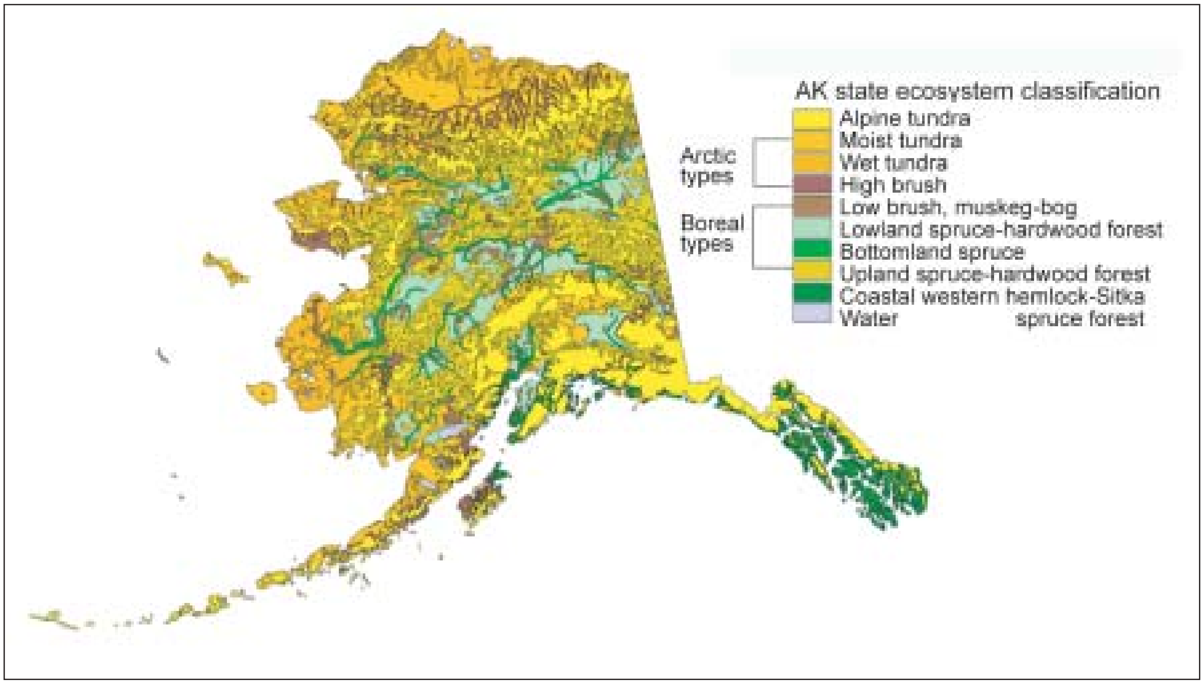

Figure 1—Major ecosystems of Alaska. Source: Markon, C. 1991. US Geological Survey digital map of the major ecosystems of Alaska. Based on the map unit boundaries delineated by the Joint Federal-State Land Use Planning Commission for Alaska in 1973. Scale 1: 2,500,000.

Table 1–Structural characteristics of major arctic-boreal vegetation and ecosystem zones

Zone	Vegetation structure	Mean July temperature
Polar desert	Mainly herbaceous or nonvascular, discontinuous scattered plants. Mosses, when present, limited to acrocarpous species or small hummocks of individual clones.	1-3 °C
High arctic	Mainly herbaceous (Graminae and Cyperaceae); woody species in genera *Salix* and *Dryas* with woody sections limited to below ground or 5 cm above ground, areas of semicontinuous cover in protected areas. Increasing diversity of pleurocarpous mosses in small clusters of plants.	4-6 °C
Low arctic	Codominated by herbaceous (mainly graminoids of Cyperaceae) and woody species in the Ericaceae family and in genera *Salix, Dryas,* and *Betula*. Woody sections to as high as 40 cm above ground. Continuous cover. Development of full moss and lichen carpet underlying vascular species with high nonvascular species diversity. *Sphagnum* spp. dominate moss carpets in certain regions.	7-9 °C
Treeline or woody tundra	Tall shrubs from 1 to 2 m tall representing four to five families, with graminoids of Cyperaceae subdominant. Scattered islands of coniferous trees, occasional stands of poplar (*Populus* spp.) or tree birches (*Betula* spp.). Increased moss biomass and production.	10-12 °C
Boreal forest	Uplands completely dominated by fully developed forest, mainly of *Picea, Betula, Populus,* and *Larix*. Graminoid-dominated stands of Cyperaceae limited to areas of permafrost in lowlands. Moss biomass and production extremely variable depending on forest type and condition, from none in deciduous upland forests to thickest development of carpets in open, permafrost lowlands.	12-15 °C

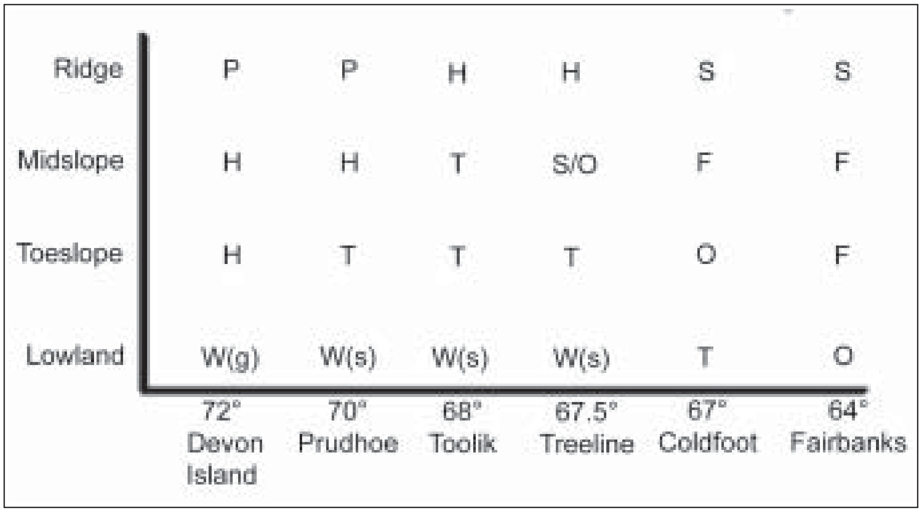

Figure 2—Arrangement of major structural-dominance vegetation types along gradients of megascale climate and mesotopography (catenas) in Alaska and western Canada. (Latitude is shown for each location.) Symbols: P–polar desert, see table 1; H–heath, ericaceous and rosaceous prostrate and dwarf shrubs with lichens; W–fen (wet meadow) dominated by species of *Carex* (s) or grasses (g), mainly *Dupontia fisheri* R.Br.; T–tussock tundra, *Eriophorum vaginatum* L., *Carex bigelowii* Torr. ex Schwein. with low and prostrate shrubs; S–shrub tundra, species of erect *Salix* L., *Betula* L., and sometimes *Alnus* P. Mill*.* with an understory of prostrate shrubs, graminoids, and mosses; O–open woodland/muskeg, combination of sparse black spruce *Picea mariana* (P. Mill.) B.S.P. with tussock tundra; F–forest, mainly *Picea glauca* (Moench) Voss as well as *Populus tremuloides* Michx. and *Betula papyrifera* Marsh*.*

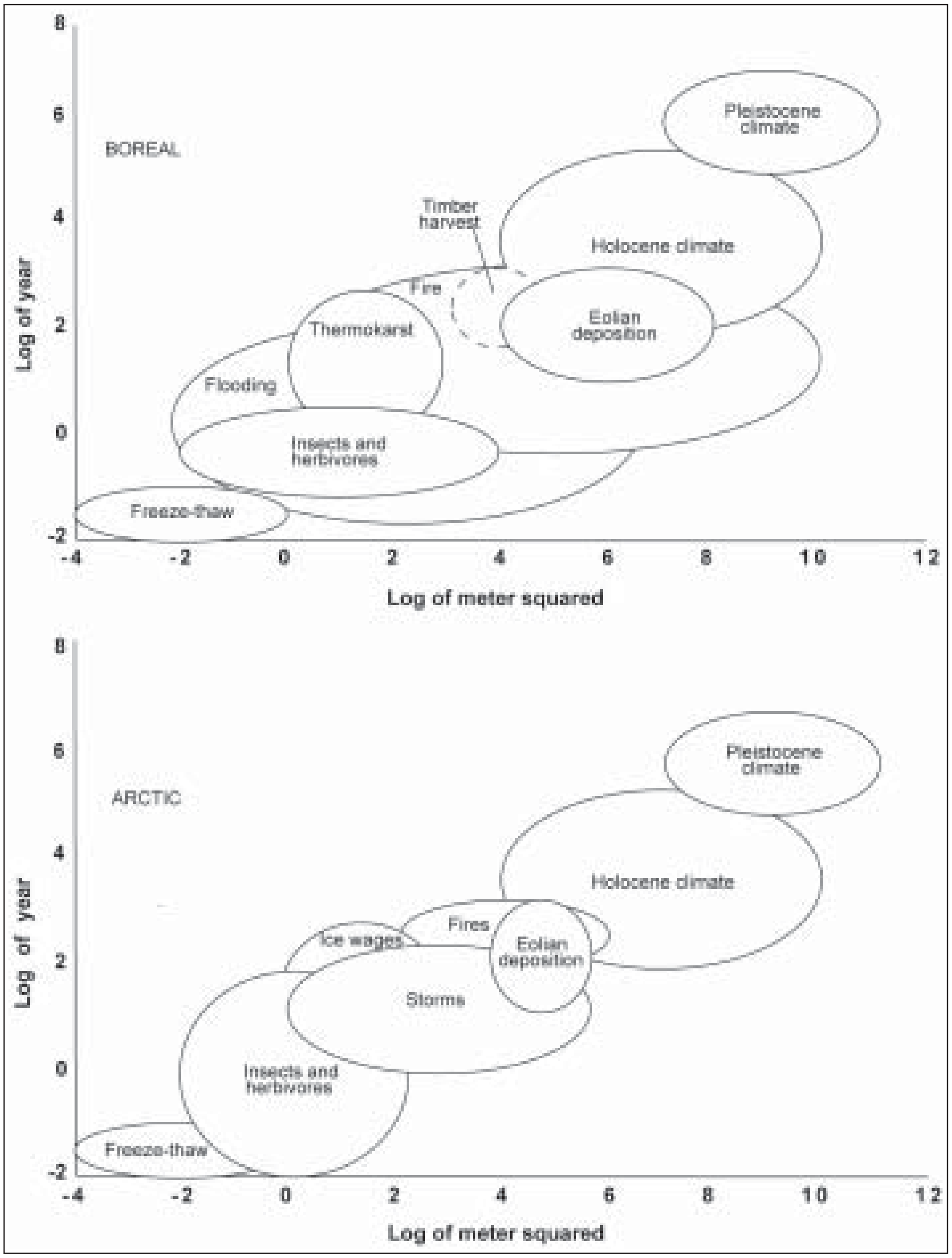

Figure 3—Spatial and temporal domains of the major landscape-forming natural disturbances in boreal and low arctic ecosystems, respectively (adapted in part from Walker and Walker 1991). Timber harvest is overlain on the boreal system to show its extent relative to other disturbances.

The increased importance of fire and animals is a direct result of the presence of trees but also is a function of climate. Climate sets an ultimate limit on tree growth and in some cases animal distribution (particularly insects; Chapin and Danell 2001), but the presence of trees also drives both insect and fire regimes. In the Arctic, patterns of vegetation and major differences in ecosystem function can be clearly linked to a series of mostly abiotic controls (Walker et al. 1994, Walker et al. 1998). Although the arctic biome in Alaska has varied significantly in spatial extent and appearance over the past million years, most of its flora formed in major glacial refugia and has since been redistributed to form existing patterns (Hultén 1937). The Alaska boreal ecosystem, in contrast, had its dominant species invade only within the past 10,000 years, in a series of "waves" that represented almost instantaneous appearance over large areas (Anderson and Brubaker 1994, Hu et al. 1993). Existing patterns within the Alaska boreal zone can be explained almost completely by a combination of mesotopography and succession following disturbance (Van Cleve et al. 1983, 1996).

The ability of a few species to play a dominant role in ecosystems processes has major implications for many management issues as well as for our ability to comprehend the potential for change in the system under changing climate. Because arctic systems are controlled by fairly fixed sets of regimes, developing comprehensible models of landscape change related to climate change should be possible (Epstein et al. 2000). In the boreal system, however, the strong interaction between biota, climate, and disturbance regime makes for a much more chaotic system (Rupp et al. 2000, Starfield and Chapin 1996). Getting fire management "right" is perhaps the single most important management question in Alaska's interior region today. Fire has more than major ecological consequence in Alaska; fire fighting is a major source of cash economy in many small villages.[2] The Alaska Fire Service's current policy is to control human-caused fires and to let natural fires (started by lightning) burn unless they threaten life or property.[3] Their goal is to support a natural regime, with the idea that ultimately such a regime will maximize all major economic landscape uses: wildlife habitat, recreation, and timber harvest. Because fire regime is so closely tied to both climate and vegetation, it seems unlikely that any policy other than the current one could be justified by scientific evidence. A natural fire regime will forever be a moving target, however, and thus management goals need to follow the regime rather than dictate it.

Forest harvest in the Alaskan interior represents a scale issue mainly in the sense that current forest harvest is on a scale small enough that it can be considered ecologically insignificant. A closer examination indicates this view to be somewhat of a falsehood, however. Most harvest is on private lands owned by regional corporations. Forest industries on these lands are not economically viable from a market perspective but are subsidized as a way of getting local timber and firewood and providing employment in small villages.[4] Harvest on public lands is primarily within the Tanana Valley State Forest and to a lesser degree on Bureau of Land Management lands. Current harvest rates on these lands are at about 800 acres per year, and many offered sales are not purchased (Crimp et al. 1997). Forest harvest is a public concern, however, for the following reasons: (1) Sustainability of the harvest resource, mature white spruce stands, is little understood and highly variable in time and space. There has been no systematic analysis of forest practices over the last 30 to 50 years to analyze changes in composition following harvest, but there is some evidence that certain harvest practices may result in a long-term dominance of deciduous species, an undesirable management outcome if white spruce harvest is to be sustained. Natural reseeding and successful establishment of white spruce are dependent on timing of cone crops and herbivore population levels, both of which vary in time, creating an uncertainty that is beyond management possibility. (2) Most harvests are in highly visible areas near roads and along rivers, and thus engender public scrutiny and debate. Although the level of harvest is essentially invisible relative to large timber industries, it is of great concern locally. (3) The Alaska economy is almost completely dependent on natural resources, both from extraction and tourism viewpoints. Changing global markets for fiber and new technologies that make fiber use more practical could potentially lead to a regional fiber industry that would not be so dependent upon certain vegetation types. Thus, although the current timber industry effect is masked by the effects of fire, fiber extraction on large scales could change this. A firm ecological

[2] Chapin, S.F., III. 2001. Personal communication. Professor, University of Alaska, Fairbanks, P.O. Box 757520, Fairbanks, AK 99775.

[3] Jandt, R. 2001. Personal communication. Ecologist, Alaska Fire Service, Bureau of Land Management, P.O. Box 35005, Fort Wainwright, AK 99703.

[4] Wurtz, T. 2001. Personal communication. Research ecologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Boreal Ecology Cooperative Research Unit, P.O. Box 756780, University of Alaska Fairbanks, Fairbanks, AK 99775-6780.

understanding of how disturbances operate in this system in time and space is therefore essential to our ability to provide input on sustainable management practices.

In conclusion, Alaska is considerably different from other states in terms of having extensive, remote landscapes that are mostly undeveloped. Management of Alaska landscapes must consider the interactions between the spatial and temporal scales of various disturbances. Both long-term data collection and retrospective analysis are important tools for understanding the frequency and importance of certain types of events. Managing for sustainability must consider that the range of variability in key disturbances will rarely match with the affected spaces and timeframes required for most management decisions.

Metric Equivalents

1 acre = 0.405 hectares

Degrees Fahrenheit = 1.8 °Celsius + 32

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Landscape Perspectives

Roger N. Clark,[1] Linda E. Kruger,[2] Stephen F. McCool,[3] and George H. Stankey[4]

In this presentation, we describe perspectives about landscapes and scales of analysis appropriate to understanding the nature of relationships between people and the environment of which they are a part. We also discuss how to improve integration of human and biophysical considerations in the study and management of landscapes. Given the purpose of this conference, the paper is not in the format of a formal review or synthesis of the literature. This paper reflects the experience of the authors whose work has collectively spanned several decades and a variety of topics related to people and natural resource interactions. Our observations might best be considered as propositions to aid discussion rather than scientific conclusions or testable hypotheses.

Landscapes Are in the Eye of the Beholder

Landscapes come in many sizes. There is no one right definition for what a landscape is (or what it means to different people) or the scale(s) appropriate for understanding relationships between humans and natural resources. Various needs and questions will define the appropriateness of landscape meanings and scales of analysis. Sometimes these needs are defined by scientists, other times by forest managers, and yet other times by citizens. Technical definitions are important for technical analyses but not necessarily important to everyone; they are a means to often-unclear ends. The challenge is to understand the needs and questions to be addressed before lines are drawn on maps and data collection started. Such problem framing is the most important, yet least well-done step, particularly if all interested parties are not included up front.

In a sense, the meanings that landscapes hold are constructed by those viewing the landscape or interacting with it in other ways. Each meaning is different, not better or worse. Full understanding of the values and meanings landscapes produce requires that analyses be inclusive of the people who interact with the landscape. The implication of different types of meanings is that conflict is likely to occur where such meanings collide.

People Think and Act at Multiple Scales for Many Reasons

No one way to divide time and space will account for the multiple values, concerns, and uses that people bring to the understanding of natural resources. Some ways to think about how landscapes can be considered from a social science perspective are summarized below.

Many values are important to people. Many values are important to people as they think about and use forests and other landscapes. These include a variety of commodity, public use, amenity, environmental quality, spiritual, and health values. Such meanings are attached to landscapes by different types of people and at different scales. For example, recreation can be thought of as people using microsites such as campsites or as driving for pleasure across larger landscapes. And the array of values often blends biophysical, economic, and social domains in different combinations across space, people, and time. This means that to understand the meaning and importance of these values, expertise beyond the biophysical sciences is required.

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Photo by Roger Clark

People organize in many ways. There are a variety of ways to think about how people (individuals) are combined at different scales and how a social organizational hierarchy can be described. These include individuals, family and household groups, neighborhoods, communities, counties/boroughs, states/provinces, nations, and ultimately, the globe. The interests (political, economic, cultural) people hold in the landscape at different scales and the decisions they make about how they interact with it may cut across these different levels. Each level or scale is characterized by different emergent properties, such that the next higher scale is not simply an aggregation of units. There are often mismatches between these organizational units and biophysical scales that need to be reconciled before any analysis begins if an integrated solution is desired. Putting the pieces together later has proven to be difficult.

People act at multiple spatial scales. These include microsites, areas (e.g., a grove of trees, meadows), drainages, watersheds, landscapes (e.g., “the valley”), regions (e.g., Puget Sound), continents, and the globe. It is important to consider such ways of defining scales because different social, cultural, and institutional properties may emerge at each scale. Appropriate scales may be defined by the processes at work, interactions within and between components of complex biophysical and social systems, and policy or scientific needs. Meanings cannot be aggregated upward; people may define an entire watershed as a suitable place for timber harvesting, yet hold claims to spiritual, aesthetic, and recreational meanings at the site level.

Human lives and activities consider multiple temporal scales. Ways of defining time include the past, today, tomorrow, weeks, seasons, years, decades, and generations. These may or may not coincide with how time is considered by specialists concerned with biophysical phenomena. Differences between biological and social scales of significance are frequently at the root of conflict—such as when forest plans are considered over a 50-year timeframe but budgets are appropriated annually. Considerations of time often influence public acceptance of forest management practices.

We must beware of the ecological fallacy when drawing conclusions about people. What may be true at a higher scale, such as the county level, may not be so at lower scales, such as the communities in the county; the attributes of a transportation system may not apply to the individual roads within; qualities of a dispersed recreation area may differ when one looks at specific sites; and the distribution of meanings across a landscape cannot necessarily be summed to arrive at an overall assignment of landscape meanings. Looking up and down this sort of scale is not

Photo by Linda Kruger

simply an aggregation or disaggregation issue. It is likely in many cases that different processes work at different scales. The perspectives people have when they think at different scales influence judgments about the appropriateness and acceptability of change. And what may be acceptable at one scale may not be so at another.

Human habitats are definable. Concepts that help explain why some wildlife species behave as they do also help explain the behavior of people. For example, we have found in studies of recreationists that home ranges exist for both residents and tourists (a migratory species!). Edges, particularly along water, affect use. Critical habitats are definable and include attributes that relate to many temporal and spatial scales. Human habitats—for recreation, spiritual, and aesthetic purposes—are dynamic in time and space. Travel corridors and how they are accessed influence patterns of use. Place attributes and meanings (at multiple scales) influence choices people make. However, the meanings people attach to specific places, and how they define their critical habitat needs, often are not correlated with certain types of biogeographical features mapped by biologists. These concepts can help us think about how people relate to landscapes at multiple scales and improve our ability to understand the effects of policy options and management practices on existing and potential public values and uses.

Corridors channel energy. Natural topography and features and human-created corridors channel air, water, critters, and people. The intersections of corridors (water crossings, power corridors, dams) or flows within them often reveal conflicts and compatibilities between public values and uses and other resource values.

Acceptance of change varies both in time and space. Judgments about the acceptability of changes depend on their nature, extent, cause, and location with respect to the meanings and values people attach to specific places and landscapes.

Problem Framing Is the Key to Success

It is important not to "start" until one gets the issues and questions right. This usually means we need to step back from individual, disciplinary definitions and join with other "–ologies" and interests. We need to be sure we are not solving "solutions" or solving the "wrong" problem. We must learn from one another about how we "see" and define landscapes so that we can jointly construct opportunities and redefine problems and issues and then develop explicit questions to drive joint actions. Action in today's society requires multiple actors, and joint agreement on problems and opportunities is needed before effective action can be implemented. It is important to determine where questions require "broad and integrated" as well as "narrow and deep" approaches. Picking the wrong boundaries and scales is inevitable unless driven by questions. Because integrated approaches require a full range of interests, types of knowledge, and points of view, such approaches will challenge the power and authority normally accorded to experts and specialists.

Problem Framing and Resolution Must Include Various Value Systems

Because landscape values and meanings differ by time, scale, and individual or group, there is no "correct" definition. Although this suggests that diversity may be an obstacle, it may be an opportunity as well. What can unite us is recognition of the power of both individual and collective perspectives. Although we "look at" the same places we "see" them differently, so to really understand them we need to look at them together and describe what we see and why. But this is not an easy task. Planning processes that are inclusive raise the possibility of increased understanding, improved representativeness in public participation, an opportunity to learn, and eventually identifying ways to get to a desired future.

What's Getting in the Way?

As we think about and conduct analyses of landscapes from multiple perspectives, it becomes evident that to develop a more holistic approach is difficult. A number of things make designing and implementing integrated approaches challenging. Ideologies and beliefs (worldviews) condition how we think. The common focus on getting answers and solutions before clarifying the questions and problems often leads us in the wrong direction. The language of science and expertise makes it difficult for interested citizens to easily engage in processes and activities that affect them and to contribute the knowledge they have about the complex systems we all value. Technology can be both a means and an end but often drives us in directions that later prove to be less than effective. For example, more and better geographic information system technology can be a hindrance if the wrong questions are under study.

Conclusions

All landscape definitions are human conventions–they do not "exist" in any objective sense. We carry expectations and definitions with us. And these expectations and definitions are dynamic. What often divides diverse interests and needs are assertions that there is one best way to describe landscapes and scales.

Integrated multiscale approaches will link humans with biophysical landscapes. But social and biophysical considerations often are not in sync at least initially. Improved problem framing before any action to collect data will improve the integration of human consideration, values, and uses into landscape analyses.

People form strong opinions about places and the characteristics of places at multiple scales. They also are concerned about the appropriateness of resource management uses (in time and space). Legacies on the land affect judgments in a different way. It is hard for some people to relate to large landscapes when they are concerned about favorite places.

So, landscapes are socially defined in multiple ways for multiple purposes from multiple perspectives. They are complex—socially and biophysically. These definitions are dynamic. Landscapes at multiple scales can be used as a means to unite and understand interactions among biophysical and social systems.

We need to take a more holistic view when thinking about landscapes. Boundaries matter—they define time and space for many relevant purposes. The trick is to look across boundaries on the map **and** in the mind.

Landscape-Level Management: It's All About Context[1]

Bruce Shindler[2]

Abstract

Forest managers and researchers are now working at a landscape level, but is our public with us? For most people, landscape-level management is not a clear concept. To better understand how citizens view landscapes, we need to go beyond attempts to "educate the public" and instead interact with citizens to promote learning, find appropriate outreach activities and simulation techniques, and directly address questions about risk and uncertainty. Various scales of analysis will be necessary, including the geographic, temporal, and normative contexts and their relevance to citizens.

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[1] **Shindler, B. 2000.** Landscape-level management: it's all about context. Journal of Forestry. 98 (12): 10-14. Reprinted with permission from the Society of American Foresters.

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Human Adaptation to Environmental Change: Implications at Multiple Scales

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Introduction

The purpose of this paper is to describe recent and ongoing work that contributes to understanding social and economic change at broad scales. In particular, the paper focuses on a recently released atlas on human adaptation to environmental change at the county level. The paper also discusses issues pertaining to data availability and geographic and temporal scales.

Issues of scale are important to understanding social and economic change. Two important considerations affect social and economic analyses at the broad scale. First, there is the wealth of secondary data collected by an array of federal, state, and, in some cases, local government agencies (Salant and Waller 1995). Frequently these data sets provide information for specific variables across multiple scales and on a relatively consistent basis for extended periods of time. Examples include the decennial census information that is available from individual census "blocks" or "block groups" and additive to the county, state, and national levels and the employment information collected at the firm level by employment security departments and provided at a range of geographic and industrial sector scales and levels of detail. The second consideration is that most of this secondary information is available only at scales defined by political units of government. Physical and biological effects often are relevant only indirectly as they have shaped the boundaries of government entities such as cities, counties, and states. Understanding the relevant secondary data available is a prerequisite to primary data collection efforts.

Winnowing this mass of information on social and economic variables and selecting the appropriate data to address the research or policy issues at hand is a formidable task. Also, there is the need to provide meaningful tabular, graphical, and geographical displays of this information as an aid to understanding and interpretation. It is in this arena that the work of the Rural Communities and Economies Team of the USDA Forest Service's Pacific Northwest Research Station has been concentrated. A related issue of interest is how different scales of the social and economic variables are hierarchically related and how these relationships impact the interpretation usefulness of the variables. Team work has focused on these three areas: (1) the collection of data on key social and economic variables for the Pacific Northwest; (2) the development of geographical displays (atlases) that include interpretations of these variables (Christensen et al. 2000, Raettig et al. 2001); and (3) the exploration of theoretical issues concerning social and economic variables and the linkages between different spatial and temporal scales.[4]

Recently in the West, several interagency, multidisciplinary, broad-scale assessments were conducted in response to, or in anticipation of, changes in resource management. These assessments include the Forest Ecosystem Management Assessment Team (FEMAT 1993), the Sierra Nevada Ecosystem Project (SNEP 1996),

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and the Interior Columbia Basin Ecosystem Management Project (Quigley and Arbelbide 1997). Social assessments at the county and community level were conducted as part of these bioregional assessments (Doak and Kusel 1997, Harris et al. 2000, Horne and Haynes 1999). Many dimensions of human life were reported on including culture, the history of human-natural resource interactions, socioeconomic conditions and trends, and measures of community resiliency and community capacity. This work expands on these efforts, by depicting other variables over different geographic and spatial scales. It also contributes to meeting the requirements for social and economic monitoring and forest planning. For instance, in the Northwest Forest Plan (NWFP) region, the record of decision for the NWFP directs agencies to conduct three types of monitoring—implementation, effectiveness, and validation—to detect desirable and undesirable changes as a result of ecosystem management (USDA and USDI 1994). Planning rules for National Forest System land also have requirements for social and economic sustainability (see for example, USDA Forest Service 1999). Finally, the work reflects appropriate roles for scientists in assessments, analyses, and monitoring activities associated with forest management.

Data Collection

The atlases focus on county-level information. For many of the social and economic indicators available from secondary sources (except for the decennial census), the county is the smallest unit for which information is disseminated or published. In the case of the commonly used economic variables such as employment and income, information cannot be disclosed or published that can be traced to an individual firm or employee (Washington Employment Security Department 1997). For other variables, such as those collected in the Current Population Survey (CPS), small sample sizes may preclude the calculation of data for smaller geographical areas. County-level data can be easily aggregated into larger scale areas such as planning regions, states, and even multistate regions. They also provide useful context for socioeconomic assessments at smaller scales, although in and of themselves may not be adequate proxies for conditions and trends at smaller scales (Beckley 1998).

An important consideration in collecting secondary data is the specific definition for the variable of interest. Employment information, for instance, is based on place of employment in the employment security and regional economic information system, but is based on place of employee residence for the decennial census and CPS. Temporal scale also is a consideration. Employment Security Department employment and wage information is often available on a monthly as well as annual basis. The decennial census collects information only once per decade with estimates provided for key census variables in intervening years.

The key economic variables depicted in the atlas include employment, income, unemployment, and economic diversity. The key social variables include population (and characteristics of the population, such as race and ethnicity), migration, education, poverty, and crime. These variables reflect key indicators that are used in social and economic assessments and studies on socioeconomic well-being. In addition to spatial and temporal scale issues, the atlases focus on absolute, trend, and relative change in the values of the variables. An example has been the documentation and interpretation of how different sectors of the wood products industry have been impacted by changes in timber harvest in the Pacific Northwest (Raettig and McGinnis 1996).

For the Pacific Northwest, work also has begun on the collection of community-level data incorporating the secondary data that are available and may ultimately include the collection of selected primary data items (Donoghue 2003). The social, economic, and resource data, such as timber harvests, assembled by the team have provided the basic information in an analysis of the Northwest Economic Adjustment Initiative (Raettig and Christensen 1999). The data and analytical work also have been resources for continuing efforts related to Northwest Forest Plan social and economic monitoring.

Atlases

The *Atlas Of Human Adaptation to Environmental Change, Challenge, and Opportunity* for the Pacific Northwest (Christensen et al. 2000), and the *Atlas of Social and Economic Conditions and Change In Southern California* (Raettig et al. 2001) provide geographical expression of change in social, economic, and timber-related variables at the county level. The Pacific Northwest atlas was designed to provide Northwest Forest Plan managers and planners with a comprehensive reference depicting the dimensions, location, magnitude, and direction of social and economic change in the Northwest Forest Plan region. Included are displays that show patterns of the social and economic diversity and health of the region. This atlas focuses on change during the period of timber harvest reduction and initial economic restructuring in the region. Most maps are based on changes in variables between 1989 and 1994.

The first section of the Pacific Northwest atlas (Christensen et al. 2000) contains five base maps that depict the region, the Northwest Forest Plan provinces, counties, population distribution, major transportation routes, and the public land ownerships. Six sections follow that address:

1. What kinds of social and economic changes have taken place in the face of reduced timber harvest? Are Pacific Northwest communities changing? If so, how?
2. What changes have occurred in the timber industry since 1990? Has timber employment changed? Is private harvest increasing?
3. Have changes in federal harvest had a significant effect on county revenues?
4. Are western Oregon and Washington and northern California singularly dependent on natural resources?
5. What federal assistance has aided cities and rural areas?
6. How have the population characteristics changed? What are the trends in migration, educational attainment, and changes in ethnicity?
7. What have been the changes in selected social issues such as rates of poverty, property and violent crimes, and alcohol-related incidences?

Specific maps displayed in these sections:

- Section 2: Change in timber harvest and wood products employment

  Change in public timber harvest
  Change in public and private timber harvest
  Change in wood products employment
  Federal lands-related payments to counties

- Section 3: Change in economic conditions: economic performance

  Unemployment rate compared to region
  Change in total employment
  Wage trends
  Wage level

- Section 4: Structural economic change

  Economic diversity
  Fastest growing nonfarm industries
  Slowest growing nonfarm industries

- Section 5: Characteristics of the population

  Change in county population
  Change in unincorporated and incorporated population growth
  Migration status and trends
  Change in ethnicity
  Educational attainment

- Section 6: Social issues

  Change in income maintenance
  Change in poverty rate
  Changes in violent crime
  Changes in property crime
  Alcohol-related incidences

- Section 7: Federal assistance

  Northwest Economic Adjustment Initiative

Accompanying the maps are text, supporting graphics, and tabular displays that interpret the information and patterns on the maps, explore the relevant issues in more depth, and provide a working tool for managers and planners.

A similar atlas was prepared as part of the socioeconomic assessment for the Southern California Conservation Strategy, a broad-scale planning effort for the four national forests in southern California (Raettig et al. 2001). This atlas covers 26 counties in southern California and includes maps for the same variables displayed for the Northwest Forest Plan region, except timber harvest information was not displayed owing to the relative insignificance of timber harvest on the four national forests of that region. Both atlases are available on CD-ROMs that include some interactive features.

Theoretical Issues and the Linkages Between Different Spatial and Temporal Scales

If social and economic variables are to be useful for managers and planners, a thorough understanding is necessary of the implications of the information displayed and the relationship between decision processes and different scales of the variables. Work has been done exploring the relationships between individual and aggregate data (the "ecological fallacy") (King 1997, McCool and Troy 1998) in political science and other social sciences. Still, other work has explored the issues of spatial data, unit definition, and scale in geographic and geographic information systems-related problems (Fotheringham and Wong 1991, Longley and Batty 1997). The Rural Economies and Community Team has work in progress that will produce a synthesis of the theoretical work that has been done in these areas (see footnote 4). Ultimately this theoretical work will provide the basis for understanding scale issues and how these issues impact the use and interpretation of social and economic variables in the planning, monitoring, and management settings that are part of the ecosystem management processes now being implemented.

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Land Use and Land Cover Dynamics: Changes in Landscapes Across Space and Time

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Introduction

Given interactions among terrestrial, aquatic, and socioeconomic systems, planning at the landscape level could benefit from including information from different scales. This paper offers examples of broader systems views that may inform natural resource managers and policymakers dealing with restoring and maintaining healthy ecosystems while addressing the demands of people. World growth in human populations and income has resulted in social, economic, and technological changes that profoundly affect the global management and use of natural resources. The world population will continue to grow, possibly from 5.9 billion in 1998 to 8.9 billion by 2050. The U.S. population also will continue to grow, particularly in the southern and western regions, with a projected increase of more than 120 million people by 2050. Projected increases in population and income will, in turn, increase demands for renewable resources. Demographic shifts, such as the aging of the population and increasing ethnic and racial diversity, will affect the patterns of demand for natural resources.

Growing human populations and associated use and consumption of the Earth's natural resources are placing more pressure on the chemical, biological, and ecological systems of the planet. Human activities are significant drivers of environmental changes on the mosaic of land uses and land ownerships (e.g., Cohen et al. 2002). Analysis of the ecosystem response to changes in these human-derived environmental factors is warranted at multiple scales, depending on the policy-relevant questions. Changes in societal values are part of the dynamics affecting forest ecosystems and influencing land management strategies (e.g., Franklin 1989), warranting a more explicit treatment of the human system in conjunction with ecosystem properties. Integrating the human dimension more directly into analysis systems is critical, as choices made by resource and land managers become increasingly important for the long-term sustainable use of our natural resources (e.g., biodiversity, wildlife habitat, carbon sequestration) within the context of suitable human welfare.

Examining the state of the land is a key part of sustainability and livability analyses. Land use changes can provide opportunities to help society adjust to changing demands for and supplies of renewable resources from the Nation's forest and aquatic ecosystems. Interfaces between land uses, such as riparian zones on forest and agricultural land, should be considered alongside growing urban areas and increased fragmentation of some forests. In this paper, I examine drivers of changes in the large private forest land base, and discuss changes in land use and land cover by major categories.

Land Base Changes Over Time

From 1800 to 1930, forest land area in the United States declined by some 300 to 350 million acres (Clawson 1979), primarily in the East. This was about a one-third loss in forest cover. Some of this land was employed for urban and infrastructural developments, but the largest portion was cleared and converted to agriculture. These land use changes reflected federal policies of the time to transfer the original public domain to private hands and to expand agricultural production. With the closing of the public domain, establishment of permanent federal forest reserves, conversion of most suitable nongovernment forest lands to some form of cropping or pasture, and dramatic improvements in agricultural productivity, the net movement of land between forestry and agriculture has become far less marked. Since 1950,

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U.S. forest land has declined about 4 percent, with the largest losses being to developed uses (Alig et al. 1999b).

Although the large amount of forest land clearing for agriculture of the last century is probably a phenomenon of the past, continued expansion of urban and developed areas is likely (e.g., Alig and Healy 1987). In 1994, forests covered 65 percent of nonfederal land in the Pacific Northwest, and these forests are under increasing pressure of conversion. Oregon's and Washington's populations have increased faster than the national average over the last decade. Most of the increase was in the western part of the region, especially along the I-5 corridor. For example, Portland was one of the fastest growing cities in the United States over the last decade. Projections are that the Pacific Northwest's share of total population will increase, as the Nation's population also expands.

Urban sprawl and livability are issues receiving increased attention around the Nation, as the Nation becomes more urban, with more than 75 percent of U.S. residents now living in cities (USDC Bureau of the Census 2002). In the Pacific Northwest (PNW), approximately 400,000 acres of forest were converted to urban and developed uses between 1982 and 1997 (USDA NRCS 2001). Such changes can interact with other environmental alterations, such as habitat fragmentation, wetland loss, loss of biodiversity, and water pollution, and the cumulative impacts on any particular ecosystem need to be considered carefully.

Socioeconomic Trends

A number of socioeconomic trends affect options for restoring and maintaining ecosystems, and affect the supply and demand of land-based goods and services. Along with the move to cities, more and more people are moving to the Nation's coasts. Some 53 percent of the U.S. population lives in the 17 percent of the land in the coastal zone (within 50 miles of a coast). Further, the largest population increases over the next several decades are projected to continue to be in coastal areas. Increases in population and personal income tend to lead to reductions in aggregate forest area (e.g., Alig and Healy 1987). Such trends need to be factored into landscape analyses, given implications for fish habitat, riparian areas, wetlands, and recreational opportunities.

In addition to an expanding population, the U.S. population is aging. Early in the 20th century, 1 in 25 Americans was over age 65. In 2000, 1 in 8 was over 65 (USDC Bureau of the Census 2002). Other demographic changes include continuing shifts in ethnic and racial compositions. The changing U.S. demographic composition likely will impact demands for forest and range resources and how resources are managed (USDA Forest Service 2001).

Americans' incomes have grown substantially (in real terms or constant dollars) in recent decades, and average per capita personal incomes in Oregon have increased more than 75 percent over the last 30 years. Projected increases in discretionary income will increase demands for renewable resources, but may also lead to further conversion of forests for developed uses.

The United States in the last decade of the 20th century was in a period of economic growth, as stock markets experienced relatively large gains. In the new millennium, wealthier nations are likely to have a greater ability to accommodate restoration and maintenance of ecosystems than are those nations with economies under serious stress. However, some development patterns may increase vulnerability of land-based systems in spite of greater wealth. With more assets and infrastructure located in coastal areas, this may complicate rehabilitation of ecosystems home to Pacific salmon. Such trends also may increase vulnerability of coastal areas to pollution and to extreme events that are under study for any linkages to global climate change (e.g., Easterling et al. 2000).

The United States is also currently in the midst of rapid changes and advancements in technology capabilities in many economic sectors. The new information technology has affected agricultural production and the forest sector to a lesser degree. Socioeconomic conditions will influence how the technology is disseminated, and this will affect how well our region and country can effect improvements in the state of the land. With growing and wealthier populations, development pressures and recreational use stresses on forests, wetlands, and riparian areas are likely to increase.

Types of Land Use and Land Cover Dynamics

Five categories of change involving the land base are (1) afforestation, (2) deforestation, (3) ownership, (4) forest type transitions, and (5) land management intensity (Alig and Butler 2002, Alig et al. 2002). Such changes arise from an interaction of biophysical, ecological, and socioeconomic processes and forces, often operating at a variety of scales. For example, market forces tend to operate at much larger scales than biophysical processes commonly studied at microlevels such as stands or reaches of a stream. I will provide a brief overview of the types of land base changes, with illustrations of temporal and spatial considerations drawn from empirically based studies. The example studies range in geographic scope from the Oregon Coast Range province (Spies, this volume) to the global level of analyses for current investigations of climate change.

Afforestation

Afforestation is the forestation, either by human or natural forces, of nonforest land. Two examples are planting conifers on former cropland and former Christmas tree plantings that are allowed to revert to "wild" forest. In the Pacific Northwest (Oregon and Washington), most afforested acres were formerly in pasture and range use. Tree planting is a major component of afforestation. Approximately 10 percent of the area of U.S. private tree planting in 1994 was in the Pacific Northwest in contrast to more than 80 percent in the South. Most tree planting in the South was on nonindustrial private lands, whereas in the PNW region, the majority was on forest industry lands. Nonfederal forest area in both Washington and Oregon has steadily declined between 1982 and 1997 surveys by the USDA Natural Resources Conservation Service (2001), indicating that conversions of forest to other uses, primarily developed uses, have in net been larger than the amount afforested. The regional net loss has been more than 300,000 acres of forest over that 15-year period.

Tree planting has been a target of various policies. The United States has a long history of forest policies that jointly pursue both economic and ecological objectives, often involving policy instruments designed to affect land use or cover. Public policies aimed at one sector have impacts, either expected or inadvertent, on another (e.g., forest sector vs. agriculture sector). In recent years policies have increasingly focused on riparian zones and incentives for promoting more favorable aquatic habitat for salmonid stocks. Many past studies have examined policy impacts by either (1) ignoring spillovers in other sectors or (2) simply "adding up" impacts across the two sectors, ignoring feedbacks or interactions through the markets for land. At times, this also has included ignoring linkages between resource conditions on public and private lands, and associated interconnections via markets.

Deforestation

Deforestation is the conversion from forest to nonforest use. Between 1982 and 1992, about 250,000 acres were deforested on nonfederal land in the region. The annual rate of conversion of forests to urban/developed uses increased in the 1990s to 32,000 acres, from the approximately 25,000 acres in the 1980s (USDA NRCS 2001), with stronger population growth and more economic activity. In total, between 1982 and 1997, the net outcome of land use shifts was a regional loss in forest area of approximately 400,000 acres. The destination of most converted forested acres was to urban and developed uses.

Ownership Change

The main ownership change between traditional ownership categories has been between forest industry (FI) and nonindustrial private forest (NIPF) owner classes. The FI land is owned by companies for the purpose of timber production (see for example, Zheng and Alig 1999). The NIPF lands compose the remainder of the private forest land base. Forest industry owns most of the private timberland in the PNW region, and generally manages forest land intensively for timber production. Land exchanges among private owners have been more common than exchanges between private and public owners (Zheng and Alig 1999). For example, Forest Inventory and Analysis (FIA) surveys in western Oregon indicate a net shift of 750,000 acres from NIPF to FI owners for 1961-94. Such changes in ownership can result in notably different land management, particularly as some private owners respond to market changes prompted by reductions in federal timber supply.

With mergers, acquisitions, and other institutional changes, there also have been significant changes within the industrial ownership category (e.g., combining Willamette and Weyerhaeuser companies in 2002). The diverse NIPF owner category also continues to change in composition. Along with this, forest fragmentation and parcelization and other factors may result in more noncorporate individual owners (e.g., Sampson 2000), but they are likely to have smaller tract sizes on average. Accompanying changes in tract size may be changes in the values and perceptions of forest landowners. New owners sometimes bring different land management attitudes compared to traditional owners, with changing values often the result of exurbanization, or urban residents moving to rural settings.

Forest Type Transitions

Within the land base retained in forests over time, changes in forest cover types are caused by a combination of natural and human-related forces. Earlier literature dealing with forests focused on forest succession and natural disturbances, with emphasis on natural forces prompting forest type changes. However, human-caused disturbances such as timber harvests now dominate in most PNW forests (Alig et al. 2000, Cohen et al. 2002). Over the last FIA survey cycle, human-caused disturbances were more frequent, by at least an order of magnitude, than recorded natural disturbances. The probability of harvesting on private lands was about 2 to 10 times more likely than full- or partial-replacement disturbances from wildfire, the primary natural disturbance agent of the past. In the approximatly 10 years between FIA measurements, timber harvests affected about 20 percent of private timberland, whereas fire affected less than 1 percent.

Given this disturbance backdrop, clearcutting Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands on FI lands resulted in 15 percent being replaced by hardwood (primarily red alder [*Alnus rubra* Bong.]) stands, and another 3 percent went to other types. Clearcutting red alder stands on FI lands resulted in 72 percent being replaced by other forest types. In contrast, only 42 percent of red alder stands on NIPF lands changed forest types after clearcutting, reflecting fewer intentional type-conversion efforts after harvest. Even for those stands not disturbed, 12 percent of Douglas-fir stands on FI lands and 23 percent on NIPF lands changed forest type. Such findings suggest that recognition of ownership differences can be important, beyond the public vs. private classifications sometimes used.

Land Management Intensity

Within a given forest type, investments in forest management can significantly influence options for different mixes of goods and services. Management intensity includes the timing and type of harvests, which have differed notably over time by ownership in this region. Investments in improved planting stock on private land have allowed higher forest production per acre in some areas, lessening pressures on other areas looked upon for nontimber goods and services. From a broad perspective, demands for different mixes of land-based goods and services are likely to shift over time with a growing and wealthier population. Because some forest-based processes are decades or centuries in length, planning such investments with adequate lead time is critical.

Assessments of Land Base Changes

The 2000 Resources Planning Act (RPA) assessment by the USDA Forest Service (2001) is designed to examine the current situation of the Nation’s forest and rangeland ecosystems and assess the prospective situation over the next five decades. In support of that national assessment, research pertaining to drivers of land use change at macroscales indicates that major determinants of land use changes are population, personal income, and potential profits from land enterprises such as forestry or agriculture (Alig et al. 2002). For example, the Forest and Agricultural Sector Model (Adams et al. 1996a, Alig et al. 1998) has endogenous determination of land use changes. The linked model of the U.S. agriculture and forest sectors has land demands and supplies in both sectors that are endogenous and determined simultaneously with demands and supplies for products from those lands. One possible objective function in the model is economic maximization (Adams et al. 1996b). Examination of land use changes within a multisector context is important for assessing alternative futures of “sustainable forestry,” “sustainable agriculture,’’ “sustainable communities,’’ or some composite.

Owner Behavior

A long-standing issue in forest resource supply studies is the likely behavior of private owners and how behavior may be affected by incentives and institutional factors. In addition to changing characteristics of the owner population over time, we also need to consider how changes in ownership objectives may impact the resources. The larger, publicly owned companies are affected by shareholder expectations, as well as pursuing acceptable rates of return on investment within a changing institutional environment of incentives and regulations. The NIPF owners, in particular, possess multiple objectives, causing them to respond to socioeconomic forces and policies in complex and sometimes unpredictable ways. Nontimber services likely could be enhanced effectively by targeting incentive programs toward select groups of NIPF owners (Kline et al. 2000). Other research has found that financial incentives are not as critical to owners' decisions in foresting riparian zones as some have suggested, and other factors include "neighborly concerns" and concerns about restrictions on land management and loss of flexibility (Kingsbury 1999). Behavior by the diverse NIPF owner group also is affected by whether owners live on their forested property in contrast to absentee owners. Another factor is increasing density of people per forested unit, especially in areas such as the Puget Sound area.

Future Directions

The landscape comprises a mosaic of the major land uses, which reflects and warrants a wide view of forces at work in shaping the landscape, in both temporal and spatial dimensions. Projections indicate that demographic and other forces will continue to affect that mosaic of land uses. If the U.S. population increases by 126 million people over the next 50 years, along with a rise in personal income, that could result in a net loss of 15 million acres of timberland (Alig et al. 2002, 2003). Future improvements in policy could be facilitated by acknowledging different ownership characteristics and a broader representation in analyses and policy deliberations of those with competing interests in the land, including public information about actions and possible consequences. With increasing populations and pressures and conflicts on the land, relationships among major land uses, such as forestry, agriculture, and urban/developed uses, are becoming more evident. Natural resource policy issues now often involve forest and nonforest components in the overall system. For example, the condition of riverine systems is affected by a broad range of land uses, and opportunities for improvements exist on both wildlands and other lands (e.g., pastureland in riparian zones). Efforts to better understand how systems function, especially terrestrial, aquatic, and socioeconomic systems, should bear in mind policy-relevant questions and consider the marginal costs versus marginal benefits of undertakings.

From a long-term conservation perspective, pursuit of new options for improvements in natural resource conditions is increasingly faced with compatibility issues among competing interests in the land and incentives for owners. Efforts to better align commercial uses of the forests with other conservation objectives has led to increased interest in what is being called sustainable forestry, although there are similar efforts tied to other major competing interests in the land, such as sustainable agriculture or sustainable communities.

When one looks at managing forested systems for multiple uses within ecological limits, then consideration of capital markets and other interconnections between sectors of the economy become more important. Policy issues associated with sustainability and planning information to aid in collective decisions about managing natural resources are affected by changing product market and institutional conditions, as in recent decades with changes tied to marked reallocation of rural land. Improvements in U.S. agricultural production technology allowed expanded agricultural production on a fairly constant land base. Less pronounced and in a lagged fashion, forest volumes have increased on a timberland base that is 4 percent smaller than the one in 1952. Demand for wood products is expected to keep growing, driven by the same population increases and economic development that affect demands for other major land uses. However, intensified timber management on the supply side represents some of the largest projected changes involving private timberland (Alig et al. 1999a, 2002), and could act to moderate or temper upward pressure on future wood prices. Private timberlands have the biological **potential** to provide larger quantities of timber in an environmentally sound manner than they do today. Many of the opportunities for intensified forest management can be undertaken with positive economic returns, but changing social and institutional aspects may affect actualization. Most of the timber management intensification opportunities in the United States are in the South and the Pacific Northwest west side. Further, more forests around the world are managed today compared to earlier decades, and this includes an expanding area of relatively productive plantations. Even if projected intensification were implemented, most of the NIPF timberland would still be concentrated in low management-intensity classes that involve naturally regenerated stands. Sustainability analyses can be enhanced if both land use and land investment options are examined. Analyses should be explicit with respect to timing of tradeoffs in addition to the growing attention given to spatial details. This would increase the usefulness of such tools in policy analyses, such as in the 2000 RPA assessment and forest carbon analyses.

Metric Equivalents

1 acre = 0.405 hectares

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Worldviews Panel

Private Landowner Perspective on Landscape Management

Carl F. Ehlen[1]

Presentation Objectives

Mason, Bruce & Girard has been asked to give you our impressions of the private landowner perspective on landscape management. To do this subject justice, we need to discuss private landowner goals and objectives, state and federal regulations, and forest land management issues as they relate to landscape management. As I prepared these remarks, I have drawn on my nearly 30 years of experience within the forest products industry while with Georgia-Pacific Corporation and through the contacts I have made while with Mason, Bruce & Girard. I have tried to capture questions we hear being asked and to hopefully give you an understanding of why these questions are important to the private forest landowners within our region. This region needs diversity, flexibility, room for dissension, and more nonbureaucratic processes. Any perceived benefits of landscape management, at this point in time, are being viewed as far outweighing the costs, which will be borne, in a large part, by the individual forest-land owner.

Private Landowners' Goals and Objectives

The first question we need to ask is, Why do people own forest land? What is their driving motivation? Is it profit, is it enjoyment of being able to manage a forest based on their own interests, is it for recreational purposes, or is it ownership for the beauty of it?

Although there are some who own timberland to enjoy it, most private landowners manage their lands with the objective of profiting from it in some manner, whether on an annual basis or over some other timeframe. There are many different ideas on what forest land management should look like, from very intensive to a hands-off approach.

These reasons for ownership will shape the landowners' goals and objectives and thus how they will proceed with operations on their property. Ultimately, these reasons also will shape how they will form any perspectives on landscape management.

State and Federal Regulations

The three Western states (Washington, Oregon, and California) have very comprehensive laws governing timberland operations. These laws primarily regulate forest management operations that have the potential to impact public resources such as fish and wildlife habitat and clean water. They may be modified somewhat, depending on the size of a given ownership, although generally speaking most will apply to all landowners if management activities occur.

Landowners, regardless of size of holdings, must determine how best to fit their goals and objectives with how these laws impact their individual ownership. For example, a landowner with small acreage with fish-bearing streams flowing through the property may have few management options as compared to a landowner whose property contains only non-fish-bearing streams and, who therefore, may have several management options. Corporate ownerships generally are large enough to work around the regulations and still meet corporate mandates.

As an example of how regulations can impact the management of our private forest lands, Mason, Bruce & Girard completed a study for the Oregon Forest Industries Council in the early 1990s to test the requirements of Oregon Senate Bill 1125. This bill, which was backed by forest landowners, set new requirements designed to spread timber harvest over the landscape by restricting clearcut areas to 120 acres in size and requiring regeneration to be 4 feet high, 4 years old, and "free to grow" before harvesting an adjacent timber stand. "Free to grow" is defined as "a tree or stand of well-distributed trees, of acceptable species and good form, with a high probability of remaining or

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becoming vigorous, healthy, and dominant over undesired competing vegetation." For the purpose of this definition, trees are considered well distributed if 80 percent or more of the area contains at least 200 trees per acre and not more than 10 percent contains fewer than 100 trees per acre. The study determined that the "free to grow" requirement, when combined with leave areas between harvest units and maximum regeneration harvest unit size, created the following:

1. Significant impacts on the size, number, distribution, and timing of regeneration harvests.
2. A slowing of the rate of harvest on individual tracts.
3. The potential for significantly increasing the miles of roads, which not only adds to a landowner's cost but also adds to the probability for increased environmental damage.
4. Land being taken out of production.
5. Increased stand fragmentation as the maximum regeneration harvest size is further reduced, thus potentially jeopardizing the ability of a landowner to fully harvest the annual growth on the property.
6. A significant reduction in the size of regeneration harvest units with the average always being less than the maximum allowed.
7. More broken ownership, which makes it more difficult to efficiently schedule harvesting activities.
8. More dispersion of regeneration units over the landscape.

Private landowners have long supported forest regulations backed by scientific evidence. Now, however, as regulatory proposals pass from scientific to political, private landowners are becoming more and more leery of what might be expected of them as they continue to manage their property and risk the potential loss of their investments.

Will more regulations, particularly if seen as political, drive more disinvestment of forest land?

Landscape Management Perspectives and Questions

Just as management goals and objectives differ among private landowners, so do their perspectives, and therefore their definitions, of landscape management. To our knowledge, there is no objective, all-encompassing definition of landscape management or what it means to the individual landowner in terms of impacting their timber resource.

Is "landscape management" providing for all public resources on every acre, or is it providing for all public resources through a mosaic of age and size classes of forests across the landscape?

Is it important that all landowners provide this mosaic, regardless of size of ownership?

Does landscape management include all landowners—private, state, and federal alike—in a given watershed or viewshed or larger area?

Are all landowners to be treated equally?

Will a landowner be able to factor in individual or corporate goals and objectives?

Given the above, we believe that the following, at a minimum, must be studied and analyzed before private landowners would even consider buying into any landscape management scheme.

Economic Analysis

"Land" or "soil" expectation is an indicator of the value of a piece of bare land as a forestry investment. As additional regulations are imposed, soil expectation values on low-site lands begin to become marginal, particularly east of the Cascade crest, but the same is true on the west side as well. This concern begins to beg the issue of disinvestment of lower site lands.

Current state and federal regulations are costly to the private landowner. To date we know of no analysis to determine the additional costs and benefits to the private landowner operating under any landscape management framework. An economic analysis is imperative, as any regulations in addition to what we have today would be extremely costly. As environmental regulation increases, we arrive at the point of getting small marginal benefits at an enormous cost, most of which will be borne by the landowner.

Has anyone taken the time to do an analysis of this sort?

Rotation Length Issues

Landowners must be able to determine the requisite rotation length for their property based on the productive capacity of the land and their goals and objectives, while at the same time being able to harvest their timber in response to market changes in accordance with current regulations.

How will landscape management schemes allow for this within the required timing?

How will final rotations be impacted?

Will landowners be allowed to set their own rotations and harvest ages depending on silvicultural objectives and market fluctuations?

Silvicultural Issues

With the serious decline in federal timber sale volume, combined with the continuing demand for wood products, many private landowners are endeavoring to harvest timber equal to the growth rates of their property. Many private landowners are investing **heavily** in various silvicultural activities to assure that their forest land is producing timber at its productive capacity. These activities include, among others, planting genetically improved seedlings, brush control, early and mid-rotation fertilization, and midrotation thinning. We are seeing a quality of forest management activities that is unprecedented. And yet, landowners continue to improve on these efforts.

Will these efforts and investments go for naught? In other words, will the financial investments in planting, vegetation control, precommercial thinning, etc. made early in the life of a rotation be lost if a landowner is not allowed to harvest his crop?

How does even-age management fit with landscape management goals and objectives?

Are we as a society only interested in how our private forest lands look and their resource protection attributes as opposed to keeping them productive and profitable while continuing to protect our public resources?

Is there a balance that can be reached between private timber production and habitat requirements?

Administration of Landscape Management Requirements

A great deal of thought must go into how landscape management issues are to be administered. These issues must be examined by each landowner rather than on a watershed or landscape basis. Problems will erupt as soon as one landowner is restricted or impacted to a greater degree than other landowners.

Who will be the regulator?

Who determines if landowners are complying with the requirements?

How will anyone be able to make a determination in an objective and legal manner?

Summary Comments

Our principal issue at this point is that we do not know what landscape management looks like nor do we know what, if anything, a private landowner will have to give up. Is this another attempt to further regulate the private landowner? Will landscape management become a form of “centralized planning?”

We do not know of any private landowner in the Northwest who does not embrace the need for the protection and the sustainability of public resources. The current regulatory framework is inherently designed to provide for both.

How one landowner’s goals fit with an adjacent landowner’s goals and how a given landowner’s operations fit within the definition of managing on a landscape scale, we assume, are still to be determined. In the end, however, private landowners must be included in any discussions of landscape management, particularly if regulatory proposals are being considered. There is too much value at stake for discussions on this issue to proceed otherwise.

Back to the Future: The Value of History in Understanding and Managing Dynamic Landscapes

Penelope Morgan[1]

Describing past conditions is part of a coarse-filter management strategy for sustaining biological diversity (Cissel et al. 1994, Haufler 1994, Haufler et al. 1996, Hunter et al. 1989, Swanson et al. 1994). A description of past ecosystem structure and its variability is useful in exploring the causes and consequences of change in ecosystem characteristics over time, and thus for understanding the set of conditions and processes that sustained ecosystems prior to their recent alterations by humans. It provides a context for interpreting natural processes, especially disturbance, and it allows variability in patterns and processes to be understood in terms of a dynamic system. Natural resource managers can use such information to evaluate the magnitude, direction, and causes of landscape change, especially change induced by people. An assessment of current conditions relative to the historical range of variability (HRV), also called natural variability, also can be used to identify management goals, particularly where those goals encompass sustainability, ecological restoration, conservation of biological diversity, and maintenance of natural processes (Hann and Bunnell 2001, Landres et al. 1999, Morgan et al. 1994, Swanson et al. 1994, White and Walker 1997). The concept is less useful when management objectives are narrowly focused on maximizing commodity production or sustaining the population of an endangered plant or animal (Landres et al. 1999).

In this paper, I give a brief overview of the HRV concept, which is also called natural variability and reference variability, and its use in understanding and managing dynamic landscapes. I briefly discuss the value and limitations of history, and then summarize what we have learned from historical ecology that is of use to managers of dynamic landscapes.

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Defining Historical Range of Variability

Historical range of variability characterizes fluctuations in ecosystem conditions or processes over time (Landres et al. 1999, Manley et al. 1995, Morgan et al. 1994, Swanson et al. 1994), and thus provides researchers and managers with a reference against which to evaluate recent and potential ecosystem change. Landres et al. (1999) defined natural variability as "the ecological conditions and their variability over space and time relatively unaffected by people." Thus, HRV defines bounds of system behavior that remain relatively consistent over time. It is described for a timeframe relevant to understanding the behavior of contemporary ecosystems and the implications for management, usually prior to the intensive influence of European-Americans and with relatively consistent climate. Many people use a timeframe of 100 to 700 years before present to interpret successional dynamics and to characterize past variation in forest structure and composition, but that depends on the available historical information and the ecosystem of interest. Historical data on disturbance occurrence and effects are increasingly limited the further back in time we look. Using recent centuries includes burning and other actions of American Indians, and encompasses climatic variability, such as the Little Ice Age. Hann et al. (1997) used the last 2,000 years as the timeframe for HRV for the interior Columbia River basin.

Utility of This Concept

The utility of this concept is based on two concepts: (1) past conditions and processes provide context and guidance for managing ecological systems today, and (2) spatial and temporal variability caused by disturbance is vital to ecosystem integrity (Landres et al. 1999). However, the utility will also depend on the management issues and the social and ecological context for decisions (Landres et al. 1999). The HRV often is used in combination with societal values and other information to identify desired future conditions (Haufler et al. 1996, Landres et al. 1999). Historical information has been used to guide management of waterflow on the Colorado River (Poff et al. 1997) and in the Everglades (Harwell 1997), and in management of fire (Brown et al. 1994, Skinner and Chang 1996) and forest structure (Baker 1992, Camp et al. 1997, Cissel et al. 1999, Gauthier et al. 1996, Hann and Bunnell 2001, Keddy and Drummond 1996, Ripple 1994). It also has been used in ecological restoration (Allen et al. 2002, Covington and Moore 1997, White and Walker 1997), and to deepen our understanding of the processes driving forest change (Lertzman et al. 1997; Lesica 1996; Mladenoff and Pastor 1993; Swetnam and Betancourt 1990, 1998; Wimberley et al. 2000). Ecosystem management often relies heavily on a description of past variability in defining desired future conditions (Christensen et al. 1996, Kaufmann et al. 1994, Manley et al. 1995).

The greatest values for characterizing HRV are understanding (1) how the processes and factors driving ecosystem change differ from one place and time to another, (2) the influence of driving variables in the past, and (3) how those driving variables might influence ecosystems today and in the future (Landres et al. 1999). Managers developed the HRV concept in a search for legally defensible strategies for sustaining biological diversity and ecological integrity.

Data for describing HRV differ in temporal and spatial scale (Morgan et al. 2001, Swetnam et al. 1999). Both natural (fire-scarred trees, pollen, charcoal, etc.) and human archives (old photographs, early survey data, etc.) are sources of historical data (Swetnam et al. 1999). Although we know more about fire history than about other disturbances, none of our fire history data are comprehensive across **both** time and space, and most are better at describing frequency than severity, size, or spatial pattern of disturbances. Few adequately inform us about spatial pattern and dynamics at the landscape scale (Morgan et al. 2001, Swetnam et al. 1999). Also, we have more data for points and small areas than we have for landscapes and watersheds (Landres et al. 1999, Morgan et al. 2001, Swetnam et al. 1999). Thus, extrapolation is required, but extrapolation from points to large areas, and from short time intervals (years and decades) to long time intervals (centuries) is problematic and fraught with error (Morgan et al. 2001). We can more readily reconstruct past vegetation structure than past processes, and when we reconstruct past forest structure, we are more confident about the number of large trees than we are about how many small trees there were (Allen et al. 2002). Hierarchy theory can be helpful in interpreting data from different spatial and temporal scales.

Historical Range of Variability and Desired Future Conditions

Comparing current and desired future conditions (DFCs) to HRV is useful for identifying management strategies and priorities (fig. 1). I sometimes demonstrate this with a ball (existing conditions) rolling around on a large plate (HRV). When conditions are within the HRV, the ball rolls around on the plate. The edges of the plate keep the ball on the plate (the system is bounded), until something pushes it over the edge (outside of HRV). Then the ball drops (change is rapid, and though it may be somewhat predictable, the ball might not return to the plate). Further, I can hold the ball steady, but doing so takes energy on my part (an external subsidy to the system in the form of human action). Now imagine a small plate representing DFCs. This plate is smaller because DFCs are typically more limited than HRV. It is possible to have all three stacked up: the ball on the small plate and both on the large plate. We do have forest ecosystems where current conditions are within the DFCs and those are within HRV. This includes, for example, some subalpine forests. In such cases (row 1 of fig. 1), our management decision might be to maintain this desirable condition, which we view as sustainable. We can, however, imagine other combinations. Many urban and agricultural areas, for instance, would be characterized with the ball on a small plate (current conditions within DFCs) but both separate from the large plate (both outside of HRV). Whether or not such conditions are sustainable depends on whether we as a society are willing to assume the external subsidies (e.g., financial subsidies to farmers, and fertilizer and herbicide made from fossil fuels), effects (e.g., quality of life and environment), and risks (e.g., climate changes).

<table>
<tr><th>Status</th><th>Graphical representation</th><th>Management action</th></tr>
<tr><td>HRV ≥ DFC ≥ CC</td><td>|…xxx...|
|___________________|</td><td>Maintain</td></tr>
<tr><td>HRV ≥ DFC ≠ CC</td><td>|……….| xxx
|___________________|</td><td>Restore</td></tr>
<tr><td>HRV ≠ DFC ≥ CC</td><td>|___________________| |…xxx...|</td><td rowspan="3">Evaluate carefully to assess risks, sustainability, and the external subsidies of DFC; reevaluate DFC</td></tr>
<tr><td>HRV ≥ CC ≠ DFC</td><td>|________xxx________| |……….|</td></tr>
<tr><td>HRV ≠ DFC ≠ CC</td><td>|__________________| |……..| xxx</td></tr>
</table>

Figure 1—Comparing both current ecological conditions (CC, xxx) and desired future conditions (DFC |———|), to historical range of variability (HRV, |_____|) is useful for identifying management actions. (Redrawn from Landres et al. 1999).

Thus, current conditions, DFCs and HRV may or may not overlap. All three or any two might be similar, or all might be different. Depending on social, economic, and political issues, restoration is suggested where desired conditions are within HRV, but current conditions are different (row 2 of fig. 1). When DFCs differ from HRV or current conditions, desired future conditions may need to be reevaluated (rows 3, 4 and 5 of fig. 1). External subsidies will be required to maintain such a condition, but people can choose to bear both the subsidies and the risk of change to the system. Ideally, scientists and managers can quantify the implications of different choices as the basis for informed decisions by the stakeholders. Haufler et al. (1996) suggest combining knowledge of HRV with knowledge of species needs to identify "adequate representation" of elements of ecosystem diversity.

Examples of Applications of Historical Range of Variability in Landscape Management

Hann and Bunnell (2001) describe the development of landscape management prescriptions based upon assessment of changes from HRV. They give examples at several spatial scales, including the mapping of historical fire regimes, current fire regimes, and condition classes reflecting the degree of change for the conterminous United States done by Hardy et al. (2001) and available on the Web (http://www.fs.fed.us/fire/fuelman). Hann and Bunnell (2001) also describe the use of HRV description, modeling succession, and identifying areas of departures from HRV as a means for prioritizing for restoration in Colorado. Their approach is similar to one applied in the Sierras by Caprio and Graber (2000). Cissel et al. (1999) contrast two approaches to landscape management in the Blue River watershed in Oregon. An approach based on using logging to approximate past disturbance regimes while also maintaining stream buffers created less forest fragmentation than an alternative based on matrix and corridors under the Northwest Forest Plan.

What Have We Learned?

Historical ecology provides many lessons. For instance, we now understand that disturbance was and is ubiquitous. At any given time, most ecosystems are in some state of recovery from disturbance. Directly and indirectly, disturbances strongly influence the structure, composition, diversity, and function of the ecological systems we manage. Further, disturbances interact, and the relative importance of disturbances varies with scale. For instance, it is likely that at some broad spatial scales, regional and global climate supercedes local fuel and topography in determining fire patterns (Swetnam and Betancourt 1998). It is likely, for instance, that El Niño drives fire patterns across the Southwestern United States (Swetnam and Betancourt 1990) and in the Patagonian region of South America (Kitzberger and Veblen 1997). The results of historical analysis can sometimes be surprising. For instance, Swetnam and Lynch (1993) found that spruce budworm (*Choristoneura occidentalis* Freeman), a defoliating insect in conifers, is more prevalent during wet than during dry years, counter to the commonly held notion that defoliation occurs in drought-stressed trees.

Scale matters. Wimberley et al. (2000) modeled the historical range of variability of old forests in the Oregon Coast Range. The historical range of variability was progressively narrower as they increased the analysis area by orders of magnitude from a small watershed to a large watershed and then to a region.

Changes in forests at the landscape scale are great and variable (Hann et al. 1997). Forests at high elevation have changed in different ways than forests at low elevations over the last 60 years, and both biophysical and social factors are correlated with different types and degrees of change (Black 1998). Although changes in fire regimes are extensive, the changes are not the same everywhere (Hardy et al. 2001, http://www.fs.fed.us/fire/fuelman).

Rigorous testing of hypotheses by using historical data has even greater potential for rapidly advancing ecological understanding. Time series analysis, comparative case studies, and analyzing synchronous events across broad spatial scales have taught us a great deal about the relative influences of climate, land use, topography and vegetation on fire regimes (Rollins et al. 2000a, 2000b, 2001; Swetnam 1993; Swetnam et al. 1999; Swetnam and Betancourt 1998), and about the interactions between insects, forests, and climate (Swetnam and Lynch 1993).

Through modeling (e.g., Miller and Urban 1999, Wimberley et al. 2000), comparison of managed and unmanaged landscapes, and examination of historical data, we are coming to understand how and why landscapes change. That understanding is very important to managers of dynamic landscapes, even when those landscapes are subject to introduced species, structures, and processes.

Implications and Challenges for Managers

We need new approaches to landscape planning that effectively integrate the three very different approaches currently applied.[2] Traditional approaches to evening out the flow of commodities have taught us a lot about modeling complex and interacting systems, but it is often difficult to incorporate ecological uncertainty and change into this approach. Conservation planning based upon corridors and matrices accommodates the needs of many species but doesn't recognize that landscapes are dynamic. Basing landscape management prescriptions on disturbance regimes builds upon our knowledge of how and why landscapes change (Cissel et al. 1994, 1999) but may not provide for the needs of species and people. Thus, we need to develop approaches to landscape planning that accommodate multiple species and processes in ecosystems subject to introduced species, processes, and human population pressure. For whitebark pine (*Pinus albicaulis* Engelm.) ecosystems, for instance, landscape planning must incorporate the needs and dynamics of grizzly bears, Clark's nutcrackers, squirrels, fire, the introduced blister rust, and climate change, along with scenic values and watershed protection. Historical information can help us to understand this system and to build models, which are then used to compare alternative futures for this ecosystem (Keane and Arno 2001).

Human-induced changes to our global, regional, and local environments pose great challenges to natural resource managers. Our climate is changing (IPCC 2001). Introduced species have altered our environment as well (Vitousek et al. 1996). Some will find HRV less useful in addressing management of ecosystems that are clearly undergoing changes that are to some degree unprecedented when coupled with human population pressures. However, effective management

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will continue to depend on our understanding of ecosystems. The ecological implications of climate change and the dynamics of ecosystems reinforce the need for a broader focus on restoring ecological integrity, resilience, and sustainability, rather than on restoring some "vignette" or past condition (Landres et al. 1999, White and Walker 1997).

The potential consequences to biological diversity are great if current forest conditions are outside of and remain outside of the historical range of variability. Consequences include increased vulnerability to stand-replacing fires where few ever occurred historically, which can put soils, streams, and fish at risk (Hann et al. 1997). This does not mean, however, that we must return our forests completely to historical conditions to sustain biological diversity. Thoughtful evaluation of change from historical conditions; evaluation of social needs; presence of exotic species, structures, and processes; and future climate all should play a role in identifying DFCs and the management alternatives to achieve them (Landres et al. 1999).

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Case Studies

Northwest Forest Plan

Nancy M. Diaz[1]

In the early 1990s, the forest industry in the Pacific Northwest was in a condition that has been described as "gridlock" (FEMAT 1993). Because of mounting evidence that old-growth forest ecosystems were declining in health and integrity, and because of the listing or potential listing of species (such as the northern spotted owl (*Strix occidentalis caurina*) and various salmon stocks) by the U.S. Fish and Wildlife Service as endangered or threatened, forest management practices were under intense criticism. Research suggested that a large proportion of the historical acreage of old growth had been lost to timber harvest, and that the remaining stands were heavily fragmented, causing risks to old-growth-dependent species (FEMAT 1993). In addition, habitat loss from roads, culverts, and degradation of riparian areas was contributing to problems with fish populations. On federal forest lands (those lands managed by the USDA Forest Service and USDI Bureau of Land Management [BLM]) within the range of the northern spotted owl (western Washington and Oregon, and northern California), a series of court injunctions against logging and delays from appeals of timber sales had resulted in a dramatic decline of timber harvest operations, with major economic, social, and political consequences.

In 1993, President Clinton convened a large group (ultimately over 100 contributors) of federal agency and university scientists, the Forest Ecosystem Management Assessment Team (FEMAT), and gave them the task of producing a plan that would both provide for viability of old-growth ecosystems and their associated species and provide for a sustainable level of economic benefits from forest products (Johnson et al. 1999). Led by Jack Ward Thomas (later Chief of the USDA Forest Service), the FEMAT group developed several options for consideration by agency officials; the selected alternative was adopted in 1994 (USDA USDI 1994) and became what is now known as the Northwest Forest Plan (NFP) (fig.1). The NFP guides management of 24 million acres of federal forest lands (including national forest and BLM lands, as well as national parks) within the range of the northern spotted owl.

The Northwest Forest Plan–An Ecosystem Management Approach

The Northwest Forest Plan was one of the earliest and largest attempts to implement what was at that time a relatively new concept in public land use planning–that of managing whole systems, including broad-scale vegetation patterns, biophysical processes, and whole suites of species. This approach has become widely known as "ecosystem management."

The NFP treats the land base as a system of interconnected parts, providing a single conservation biology strategy for wildlife, plants, fish, and fungi associated with late-successional and old-growth forests. The old-growth orientation of the NFP distinguishes it from other biodiversity conservation efforts. It weaves together efforts targeted at individual species potentially at risk (the "survey and manage" component, described in the next section), with broad-scale strategies that sweep in groups of species and ecological processes (reserves, special guidelines for actively managed areas). It specifically provides for active management for both commodity production and restoration. And finally, it is a long-term plan (100-year timeframe in which target conditions become fully implemented) with checkpoints along the way to determine if adjustments are needed in order to meet the goals.

A primary feature of ecosystem management is that it is science based. To achieve sustainability, plans must be built with an understanding of the

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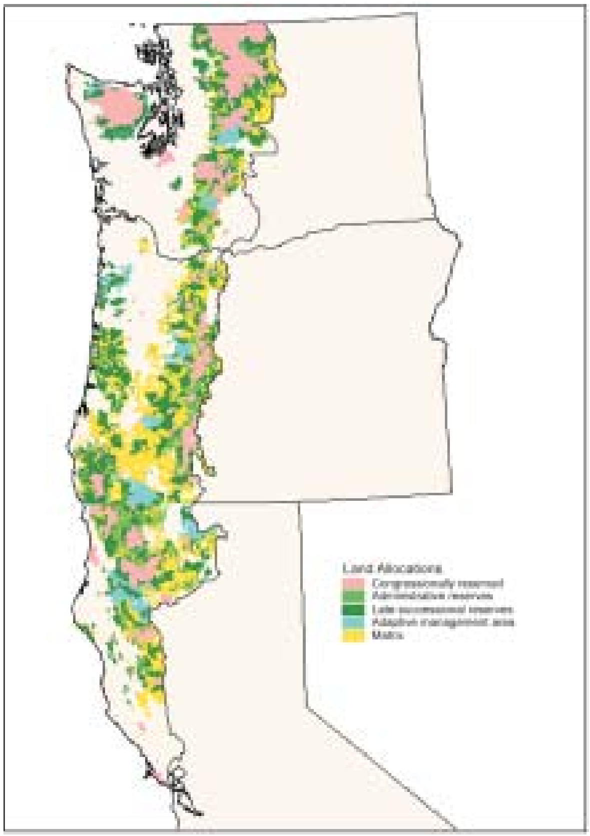

Figure 1–Federal land allocations within the range of the northern spotted owl.

interactions and possibilities among the components of forest ecosystems and their associated human communities. The NFP not only incorporated science, it was developed largely by scientists. This mode of plan development helped gain the scientific credibility needed to reverse the court injunction against timber harvest, and as the plan proceeded to be implemented, resulted in significant growth in scientist-manager collaborations.

The NFP includes three major facets:

- A strategy (composed of land allocations and standards and guidelines) for managing 24 million acres of federal forest land.
- The Northwest Economic Adjustment Initiative, a $1.2 billion program (spread over 5 years) that provides support to timber-dependent communities, tribes, and businesses.
- An interagency model of policymaking, wherein the participating federal agencies act as partners in formulating policies and major implementation steps. The participating agencies are:
    - o USDA Forest Service—Pacific Northwest and Pacific Southwest Regions, and Pacific Northwest and Pacific Southwest Research Stations
    - o USDI Bureau of Land Management
    - o USDI National Park Service
    - o USDI Fish and Wildlife Service
    - o USDI Geological Survey
    - o U.S. Environmental Protection Agency
    - o USDC National Marine Fisheries Service
    - o U.S. Army Corps of Engineers
    - o USDI Bureau of Indian Affairs
    - o USDA Natural Resources Conservation Service

Northwest Forest Plan Land Allocations, Standards, and Guidelines

The heart of the NFP is in the system of reserves, actively managed lands (matrix), and operational guidelines it lays out. The key features are:

- Matrix lands–Making up about 16 percent of the total NFP acreage, matrix lands are where most active timber harvest is expected to occur. Within managed areas, special standards and guidelines protect elements of late-successional and old-growth forests to provide connectivity for old-forest-dependent organisms across the landscape, and provide refugia for them during the time that managed areas are in earlier successional stages. These standards include leaving 15 percent of mature green trees in managed areas and specific requirements for protection of snags and large down wood.
- Late successional reserves (LSRs)–About 7.5 million acres (31 percent of the total) of federal forest lands within the NFP area are in large reserves within which late-successional and old-growth forest structures and processes are maintained and protected. The purpose of LSRs is to provide large blocks of habitat for species associated with old forests. The LSRs

are scattered throughout the NFP area such that organisms can disperse among them across the entire area (standards for intervening matrix areas help provide connectivity across managed lands). Significant acreage in LSRs is currently in younger stands (former plantations); up to age 80, silvicultural treatments may be used to foster old-growth stand structures and habitats. Once a stand reaches age 80, no further management typically occurs.[2] All activities (for example, recreation) in LSRs must be neutral or beneficial with regard to late-successional and old-growth qualities. When LSRs are combined with other types of reserves (congressionally and administratively designated areas, such as wilderness areas and national parks), the resulting acreage is approximately 78 percent of the total NFP area.

- Aquatic conservation strategy (ACS)–The NFP provides for the viability of native fish stocks and overall riparian values through the ACS. There are four components to this element of the NFP:
    - Riparian reserves–Similar in policy and intent to LSRs, riparian reserves consist of buffers of varying widths (generally 100 to 300 feet) adjacent to all streams and wetlands in the matrix. About 11 percent of the total NFP acreage is in riparian reserves. Besides providing benefits to both riparian and aquatic habitats and processes, riparian reserves also provide late-successional habitat connectivity across the matrix between LSRs.
    - Key watersheds–Selected watersheds within the NFP area are designated as "key watersheds," with special requirements for the protection of at-risk fish stocks and water quality.
    - Watershed analysis–A "systematic procedure to characterize the aquatic, riparian, and terrestrial features within a watershed," used to "refine riparian reserve boundaries, prescribe land management activities, including watershed restoration, and develop monitoring programs" (USDA USDI 1994).
    - Restoration–Special emphasis has been placed on proactively identifying and restoring degraded aquatic and riparian sites (e.g., road crossings with inadequate culverts or stream reaches with insufficient large instream wood.
- Monitoring and adaptive management–A prime goal of the NFP is to learn from experience, and adjust the plan when appropriate. This cycle of doing, learning, and adjusting is termed "adaptive management." Much of adaptive management application occurs informally and opportunistically. Two "institutionalized" facets of adaptive management in the NFP are:
    - Monitoring–The NFP calls for monitoring at multiple scales for an array of factors. The most formalized monitoring occurs at the NFP area-wide scale, in ongoing, systematic assessments of northern spotted owl populations, marbled murrelets (*Brachyramphus marmoratus*), aquatic and riparian conditions, late-successional and old-growth habitats, and adherence to NFP guidelines in implementation of land management activities. Monitoring for biological diversity, socioeconomic factors, and tribal relations is being planned as well.
    - Adaptive management areas (AMAs)–Ten areas were designated AMAs in the NFP, constituting about 6 percent of the total acreage. The AMAs were geographically located to capitalize on opportunities to develop partnerships ("collaborative stewardship") with local communities, and were intended to be places where experimentation outside the matrix standards and guidelines would be allowed (to test the adequacy of the standards and guidelines) and where new management approaches could be developed and tested.

[2] There may be exceptions to this rule on a case-by-case basis, if needed, to reduce risk to old-growth characteristics. For example, without thinning or other mechanical treatments for fuels reduction and enhancement of stand structure, some stands on the eastern flank of the Cascades with a high-frequency, low-intensity natural fire regime may be at risk of stagnation, insect and disease outbreaks, or destruction by wildfire. Conceivably, treatments after age 80 could be allowed in these stands; however, such exceptions have not been widely sought.

- Survey and manage (S&M) mitigation–When the consequences of implementing all the components listed thus far were evaluated, it was determined that there were still approximately 400 species of old-growth-associated plants, animals, and fungi whose persistence was still uncertain. For many of the species, lack of information on distribution and abundance was a major factor in their being included. This is not surprising, as the group contains many rather obscure nonvascular plants, fungi, invertebrates, and arthropods, in addition to the better known flora and fauna. The NFP sets out a special set of rules mandating surveys for S&M species prior to implementing management activities, and various degrees of protection, depending on the needs. Provision was made for S&M species to be evaluated periodically as new information is obtained, with the goal of eventually either determining that species should not have been included in the first place, or providing an adequate plan of protection.

Has the NFP Succeeded?

For the most part, it is too early to tell whether the NFP has succeeded in meeting its goals. Certainly, the harvest levels envisioned have not been achieved, largely because of recent lawsuits, lack of political support for harvest of old-growth forests on matrix lands, and other factors. Results of monitoring efforts for species and aquatic/riparian systems are still several years away. Agencies are still struggling with adaptive management, both as a concept, and in the context of the AMAs. On the other hand, the injunction against timber harvest was lifted, the agencies involved are working together proactively and collaboratively, and communities are increasingly involved in management decisions.

In 1998, the Interagency Steering Committee (ISC) commissioned a review of the NFP (Pipkin 1998). The report identified several elements of the NFP as “useful and proven models” worthy of inclusion in future assessments:

- A common regional “vision” for forests and the timber economy that all participants can work toward.
- “Institutionalized” collaboration (standing committees and chartered groups with specific mandates) among agencies and the public.
- Provision for direct participation by nonfederal governments including tribes.
- Consistent data collection and mapping across ownerships.
- Specific inclusion of research and monitoring for decisionmaking and adaptive management.

Challenges

The NFP was the first plan of its kind to attempt such a comprehensive, ecologically based effort with diverse agencies on a large land base. As plan implementation has proceeded, questions and issues have emerged that present significant challenges to the interagency partners.

At the head of the list of compelling questions is that of **meshing ecosystem-based and single-species approaches** to conserving late-successional and old-growth biological diversity. Except for the survey and manage component, the NFP assumes that providing for adequate habitat, connectivity, and ecological processes across the landscape will protect biological diversity. The FEMAT group viewed this assumption as a hypothesis that would be tested through monitoring, with subsequent plan adjustments if necessary.[3] However, an experimental approach to land management presumes that some degree of risk is acceptable, a point around which there clearly is lack of consensus. On the other hand, attempting to manage a large set of cryptic species at a very low level of risk is far beyond the resources of any of the agencies; in fact, it is probably an unattainable goal to begin with. Strategies that minimize risk to individual species by focusing on providing habitat may be the only practical solution to biodiversity conservation concerns. How to create such strategies that are scientifically sound and legally defensible remains a productive avenue for further exploration.

[3] To date, a framework for testing this hypothesis has not been developed.

The **need to work at multiple scales** was explicitly stated as a goal for the NFP (FEMAT 1993). However, technological tools for sliding up and down the continuum of scales of space and time have been slow in coming. Such tools would have to provide the ability to both scale up (for example, assemble the cumulative effects of finer scale phenomena) and scale down (disaggregate larger scale phenomena into smaller temporally or spatially explicit fragments). Currently, the NFP is being implemented at several scales (stand, watershed, landscape, province, region), but it is often impossible to translate data, findings, or effects to larger or smaller scales because of inconsistencies in methodologies, assumptions, and so on.

There is an apparent tension between what I will term **static versus dynamic approaches** to defining target conditions for a variety of ecosystem elements within the NFP. The static approach is manifested in the creation of rules, standards, and guidelines that set a threshold or narrow range of conditions that must be achieved and maintained. This approach often has the terms "regulatory" or "statutory" applied to it. In contrast, the dynamic approach is evidenced in the notion of adaptive management (experimental management with a specific goal of learning and potentially adjusting practices), and in the idea that because ecosystems are themselves dynamic, a wider range of conditions will naturally (and should be allowed to) exist through time. Both approaches have a place in the NFP, but the extent to which each applies to the various components of the NFP has yet to be resolved. The main difference between the approaches is the perception of risk associated with variation.

One of the most problematic examples of the tension between the two approaches has been in adaptive management areas. Although AMAs were delineated with the express purpose of evaluating the assumptions of the NFP through testing a wide range of practices (some of which may fall outside standards and guidelines), land managers have been understandably reluctant to venture outside the prescriptions of the NFP because of the very real threat of appeals, lawsuits, and other forms of resistance from outside entities that may lack confidence in managers' abilities to meet broad NFP goals. There are also differing points of view among the agencies regarding how much and what type of experimentation is appropriate within AMAs.

Another example is fire-prone late-successional reserves on the east flank of the Cascade crest, where managers have hesitated, again because of the risk of appeals and lawsuits, to seek exemptions from LSR guidelines in order to implement prescriptions that may reduce the risk of stand damage from fire and insects. Both of these examples illustrate that application of a static set of rules to an inherently dynamic situation may actually increase risk in the long run (through lost opportunities for learning and improved management in the case of AMAs, and through increased threat to old-growth values in LSRs).

Finally, because the NFP applies exclusively to federal lands, the **role of nonfederal lands, especially private lands**, in the overall ecological, social, economic, and political context of the region cannot be fully assessed. It is especially difficult to understand how private lands contribute to the overall whole when large elements are unregulated and landowner behavior is difficult to predict.

The federal agencies involved in the NFP have set in motion numerous efforts to resolve these and other issues. The NFP has not proved to be the ultimate solution to conflicts over the use and management of federal forest lands in the Pacific Northwest. Although the agencies have achieved major successes, small and large, the challenges listed above, combined with the continuing need to build public trust, have constituted real barriers. The NFP's strength lies in the strong science underpinnings on which it is founded, in the scope of the ecological, social, and political issues it attempted to address, and in its built-in flexibility to adapt and improve. It remains to be seen whether the agencies and public together can capitalize on these strengths to overcome the difficulties cited here and realize the NFP's promise of protection for old-growth ecosystems while contributing to regional economic health.

Metric Equivalents

1 foot = 0.304 meters

1 acre = 0.405 hectares

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Recent Changes (1930s–1990s) in Spatial Patterns of Interior Northwest Forests, USA[1]

P.F. Hessburg,[2] B.G. Smith,[3] R.B. Salter,[2] R.D. Ottmar,[4] and E. Alvarado[5]

Abstract

We characterized recent historical and current vegetation composition and structure of a representative sample of subwatersheds on all ownerships within the interior Columbia River basin and portions of the Klamath and Great Basins. For each selected subwatershed, we constructed historical and current vegetation maps from 1932 to 1966 and 1981 to 1993 aerial photos, respectively. Using the raw vegetation attributes, we classified and attributed cover types, structural classes, and potential vegetation types to individual patches within subwatersheds. We characterized change in vegetation spatial patterns using a suite of class and landscape metrics, and a spatial pattern analysis program. We then translated change in vegetation patterns to change in patterns of vulnerability to wildfires, smoke production, and 21 major forest pathogen and insect disturbances. Results of change analyses were reported for province-scale ecological reporting units (ERUs). Here, we highlight significant findings and discuss management implications.

Twentieth-century management activities significantly altered spatial patterns of physiognomies, cover types and structural conditions, and vulnerabilities to fire, insect, and pathogen disturbances. Forest land cover expanded in several ERUs, and woodland area expanded in most. Of all physiognomic conditions, shrubland area declined most due to cropland expansion, conversion to semi- and non-native herblands, and expansion of forests and woodlands. Shifts from early to late seral conifer species were evident in forests of most ERUs; patch sizes of forest cover types are now smaller, and current land cover is more fragmented. Landscape area in old multistory, old single story, and stand initiation forest structures declined with compensating increases in area and connectivity of dense, multilayered, intermediate forest structures. Patches with medium and large trees, regardless of their structural affiliation are currently less abundant on the landscape. Finally, basin forests are now dominated by shade-tolerant conifers, and exhibit elevated fuel loads and severe fire behavior attributes indicating expanded future roles of certain defoliators, bark beetles, root diseases, and stand replacement fires. Although well intentioned, 20th-century management practices did not account for landscape-scale patterns of living and dead vegetation that enable forest ecosystems to maintain their structure and organization through time, or for the disturbances that create and maintain them. Improved understanding of change in vegetation spatial patterns, causative factors, and links with disturbance processes will assist managers and policymakers in making informed decisions about how to address important ecosystem health issues.

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[1] **Hessburg, P.F.; Smith, B.G.; Salter, R.B.; Ottmar, R.D.; Alvarado, E. 2000.** Recent changes (1930s–1990s) in spatial patterns of interior Northwest forests, USA. Forest Ecology and Management. 136: 53-83. Reprinted with permission from Elsevier.

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Landscape Methodology

Analysis and Communication of Monitoring Data With Knowledge-Based Systems

Keith M. Reynolds[1] and Gordon H. Reeves[2]

Introduction

Several broad-scale ecoregional assessments have been conducted in the United States in recent years (Everett et al. 1994, FEMAT 1993, SNEP 1997, USDA FS 1996), and several more are in progress. Each assessment has used a now well-standardized approach to define the analytical problem. A scoping process was used to identify and evaluate critical issues deserving consideration. A needs assessment was performed to identify data requirements and analytical methods needed to respond to the issues. A wide array of statistical, simulation, and optimization procedures has been used to address various components of the overall assessment problem. To assert that the suite of analyses used in these assessments was conducted ad hoc would be a disservice. However, it is fair to say that, although assessment teams may have carefully coordinated the conduct of analyses with integration in mind, there is little evidence in the reports that effectively integrated analysis was achieved.

Landscape Analysis With Ecosystem Management Decision Support

The USDA Forest Service Pacific Northwest Research Station released the first production version of the ecosystem management decision support (EMDS) system in February 1997. The EMDS integrates a knowledge-base engine into the ArcView[3] (Environmental Systems Research Institute, Redlands, CA) geographic information system (GIS) to provide knowledge-based reasoning for landscape-level ecological analyses (fig. 1). Major components of the EMDS system include the NetWeaver knowledge-base system, the EMDS ArcView application extension, and the assessment system (Reynolds 1999a, 1999b; Reynolds et al. 1996, 1997a, 1997b).

A knowledge base is a formal logical specification for interpreting information and is therefore a form of meta database in the strict sense (Jackson 1990, Waterman 1986). Interpretation of data by a knowledge-base engine (a logic processor) provides an assessment of system states and processes represented in the knowledge base as topics. Use of logical representation for assessing the state of systems frequently is desirable or necessary. Often, the current state of knowledge about a problem domain is too imprecise for statistical or simulation models or optimization, each of which presumes precise knowledge about relevant mathematical relations. In contrast, knowledge-based reasoning provides solutions for evaluating this more imprecise information, and some knowledge-based systems can provide useful analyses even in circumstances in which data are incomplete.

Knowledge-based solutions are particularly relevant to ecosystem management because the topic is conceptually broad and complex, involving numerous, often abstract, concepts (e.g., health, sustainability, ecosystem resilience, ecosystem stability, etc.) for which assessment depends on numerous interdependent states and processes. Logical constructs are useful in this context because the problem can be evaluated as long as the entities and their logical relations are understood in a general way and can be expressed by subject matter authorities.

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[3] The use of trade of firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

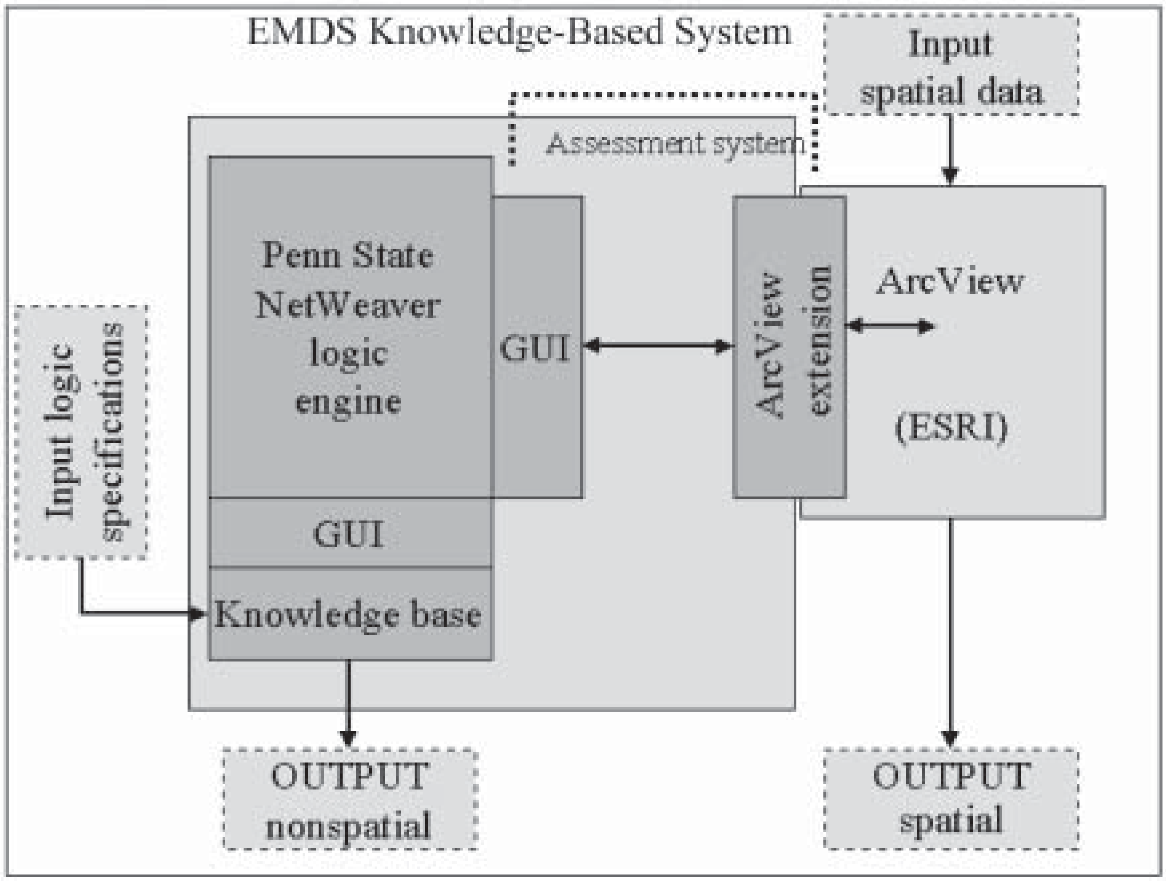

Figure 1—Architecture of EMDS system. The acronym, GUI, indicates a graphic user interface through which a user interacts with components of the EMDS application. The assessment system uses a custom GUI to manage communication between the NetWeaver logic engine and code internal to the EMDS ArcView extension. ESRI = Environmental Systems Research Institute.

Nestucca Basin Example: Evaluation of Salmon Habitat Suitability

The Nestucca basin is a 5th-code hydrologic unit located in the northern portion of the Oregon Coast Range province (fig. 2) and contains 45 true and composite 6th-code watersheds. In 1998, a watershed assessment team from the Siuslaw National Forest rated each true 6th-code watershed in the basin with respect to its suitability for providing salmon habitat, following the rating system of the decision matrix of the National Marine Fisheries Service (NMFS). In subsequent discussions with the authors, assessment team members expressed a number of reservations about the approach that had been used for rating watershed condition.

To improve on the basic approach to watershed evaluation for salmon habitat suitability as required to implement the Aquatic Conservation Strategy of the Northwest Forest Plan, the authors designed a prototype knowledge base suitable for application to true 6th-code watersheds in the Oregon Coast Range province (fig. 2). Starting with basic requirements identified in the NMFS matrix, Reeves summarized logical requirements for the knowledge base. The authors then worked together to implement the knowledge-base design in NetWeaver, and then reviewed the initial design with the assessment team to make refinements, corrections, and additions to the initial version.

The most basic outputs from an EMDS analysis are maps of evaluated indices for topics included in an analysis. In our example, the primary map of interest (fig. 3) displays the evaluated index for salmon habitat suitability for each 6th-code watershed in the basin. Composite watersheds, for which the knowledge base was not designed, are

Figure 2—The Nestucca basin is in the central Oregon Coast Range.

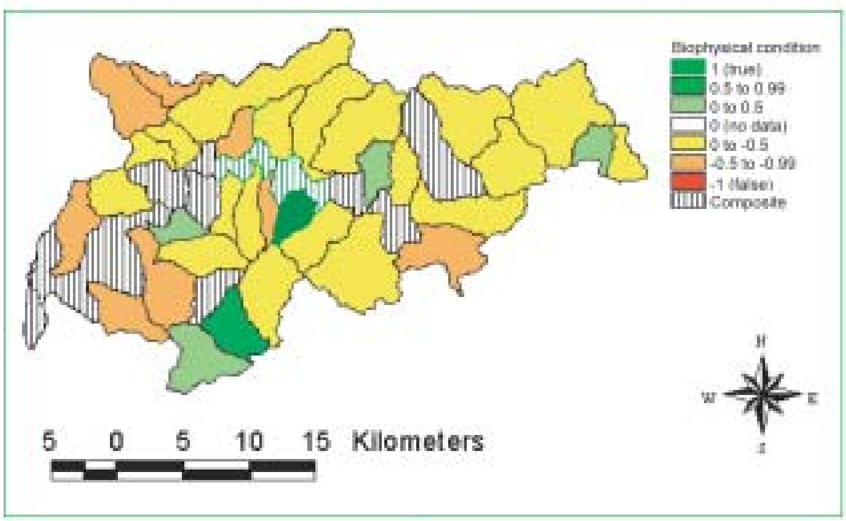

Figure 3— Salmon habitat suitability in 6th-code watersheds in the Nestucca basin. Patterned features are composite watersheds for which the knowledge base is not appropriate. The scale expresses strength of support for the proposition that the biophysical condition of a watershed provides suitable salmon habitat. The extremes of the scale, -1 and 1, indicate no support and full support, respectively. Intermediate values express some degree of support.

displayed with a lined pattern. All information that is logically antecedent to topics selected for analysis also must be evaluated by the logic engine and so is displayable either in maps, graphs, or in tabular output generated by the logic engine.

Maps characterizing landscape condition are powerful communication tools, but it is at least as important to be able to explain the basis for observed results in a clear, intuitive manner. One of the most significant features of knowledge-base systems is their ability to display a logic trace that explains the derivation of conclusions. In this example, the top portion of the browser window displays an expandable outline of knowledge-base structure, and the bottom portion displays the logic structure of the topic currently selected in the outline (fig. 4).

The NetWeaver logic engine reasons with incomplete information, when needed, by using fuzzy math (Zadeh 1965, 1968), and the engine evaluates the influence of any missing information with respect to its contribution to completeness of an analysis. Input data for the Netsucca basin analysis contained a few missing observations on data fields (fig. 5). However, the engine implements evidence-based reasoning, producing partial evaluations of topics with incomplete information (figs. 3 and 4). The knowledge base is, in effect, a mental map of the problem. Its structure contains information that can be used to compute the influence of missing information (fig. 6). The computation of influence is based on the level at which information enters the logic structure, how many references there are to it, and how frequently the associated database field contains missing observations. The assessment system in EMDS also includes tools to optionally synthesize information about data influence and the logistics of acquiring data to prioritize data needs (Reynolds 1999a).

Finally, the logic engine generates tabular output from which an analyst can summarize additional information such as the frequency distribution of index values (fig. 7) or the frequency with which data substantially contribute to a particular conclusion (figs. 8 and 9). Frequency distributions of indices provide a simple synoptic view of conditions over an assessment area at a point in time (fig. 7), and useful statistical inferences about the efficacy of restoration programs, for example, could be drawn from comparisons of such frequency distributions over consecutive assessment times. Similarly, more detailed summaries of conditions in an assessment area (figs. 8 and 9) provide useful background information for design of restoration programs as well as a basis for more detailed statistical inferences about the efficacy of these programs.

Identifying Restoration Objectives and Criteria

Problem specification for ecological assessment may well deserve to be classified as a wicked problem (Allen and Gould 1986). Evaluation monitoring must consider potentially numerous states and processes of biophysical, social, and economic components of an ecosystem. Many entities may have both deep and broad networks of logical dependencies as well as complex interconnections. Although constructing such complex representations in NetWeaver is not trivial, it is at least rendered feasible by the precision and compactness of fuzzy logic relations, and by the graphic, object-based representation of logic networks in the system interface. No subject-matter authority, nor for that matter any group of authorities, is capable of holding a comprehensive cognitive map of such a complex problem domain in their consciousness. On the other hand, the graphic, object-based form of knowledge representation in NetWeaver is highly conducive to the incremental evolution of knowledge-base design from simple to complex forms.

Two essential aspects of the knowledge-based approach to evaluation monitoring that we have described and illustrated are its goal orientation and use of formal logic in problem specification. The implications for realizing truly integrated analysis are significant. Knowledge-base design begins with identification of the questions (formulated as propositions) that the analysis ultimately is designed to address. Specification proceeds by identifying lines of reasoning that decompose the original propositions into progressively more concrete ones until links to data are identified. The result, effectively, is a mental map of the problem, including not only identification of all topics pertinent to the problem, but their logical interdependencies. The final specification thus not only provides logical links between data requirements and the original motivating questions, but provides a specification for how the data are to be interpreted, taking into account interrelations among pieces of information.

Figure 4—The knowledge base with the EMDS hotlink browser tool displays the state of the knowledge base for features (e.g., watersheds) selected in the EMDS Assessment View.

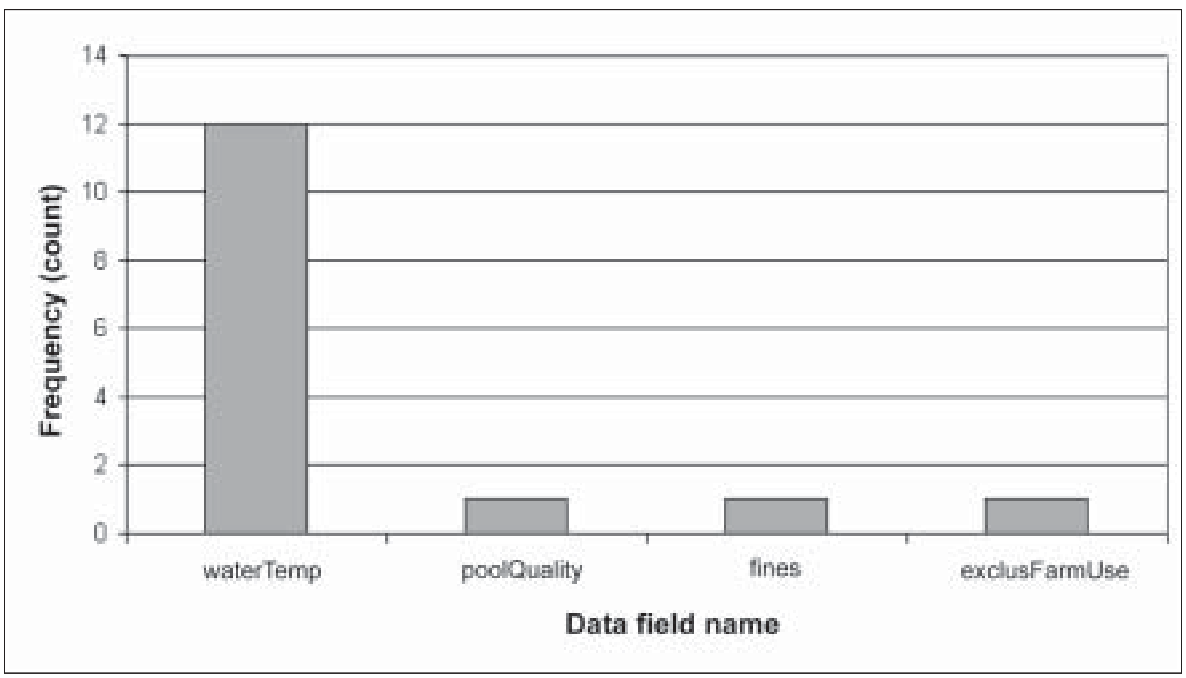

Figure 5—Frequency of missing data fields in the input data table for the Nestucca basin analysis.

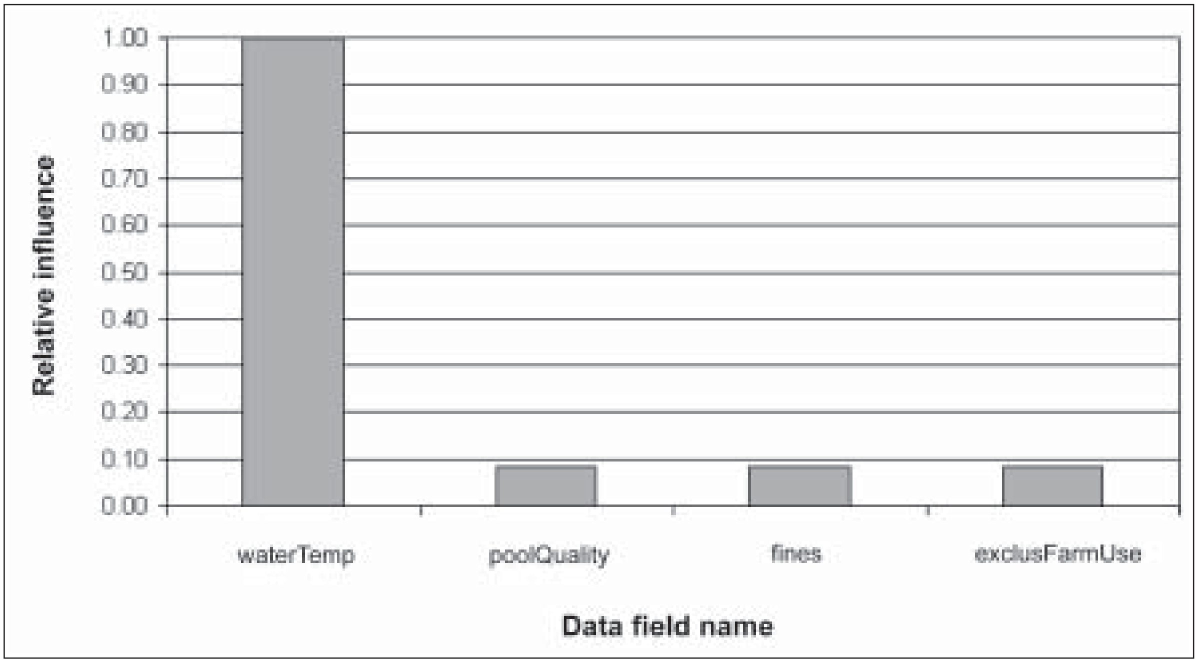

Figure 6—Influence of missing information in the Nestucca basin analysis calculated by the NetWeaver logic engine.

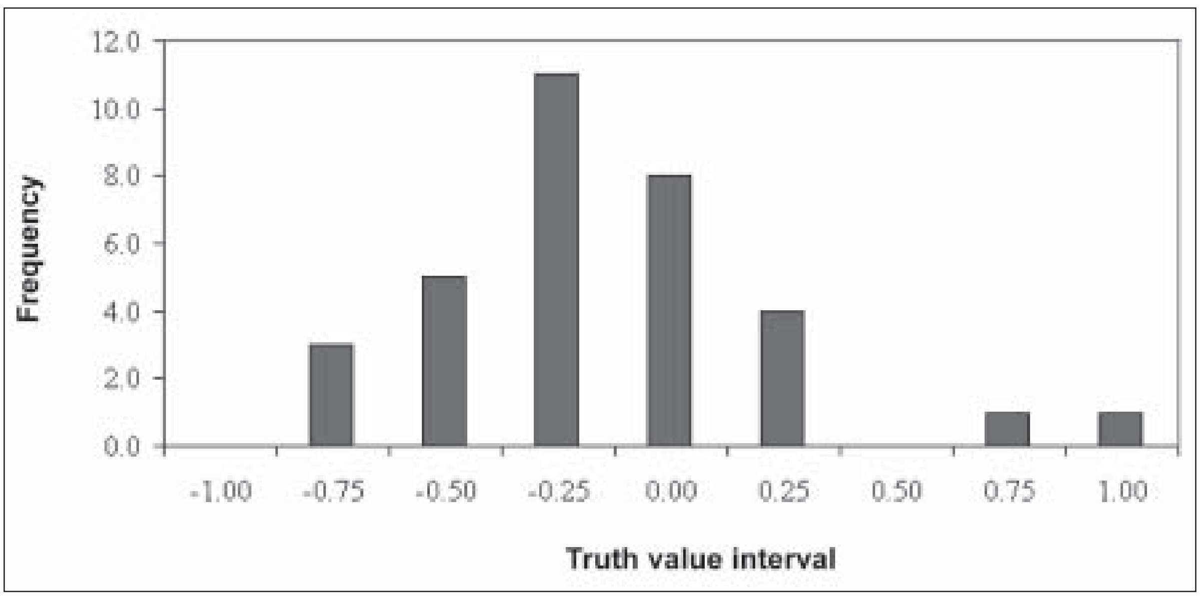

Figure 7—Frequency distribution of the salmon habitat suitability index for the Nestucca basin analysis. Truth value interval is a measure of the degree of support that data provide for a proposition. This index also can be interpreted as a measure of suitability.

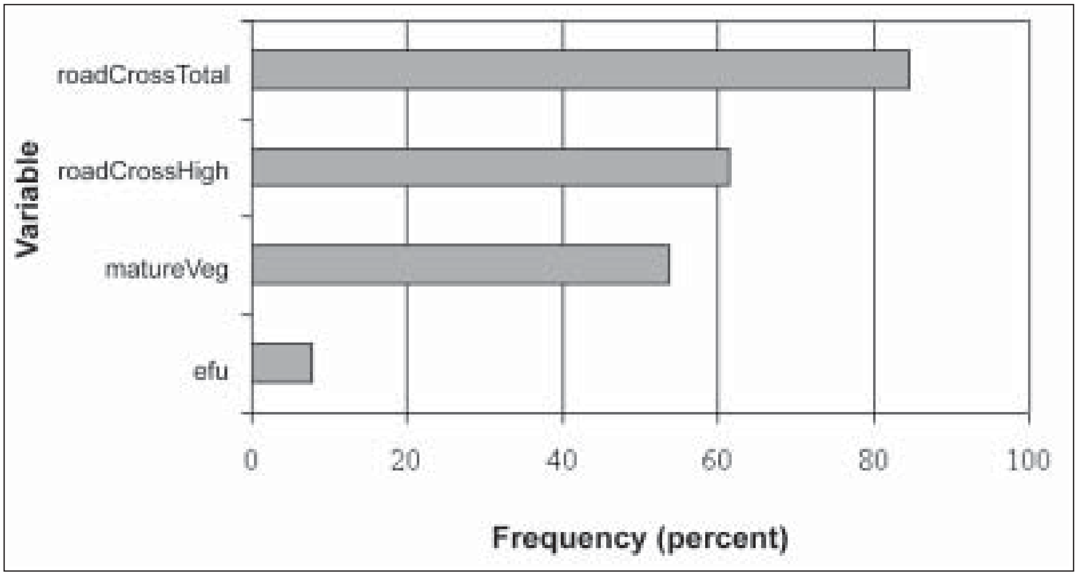

Figure 8—Frequency with which data in high-gradient drainages contributed to the conclusion of a compromised or degraded biophysical condition. Drainages with an average reach gradient greater than 4 percent were classified as high gradient; in-channel conditions were not available.

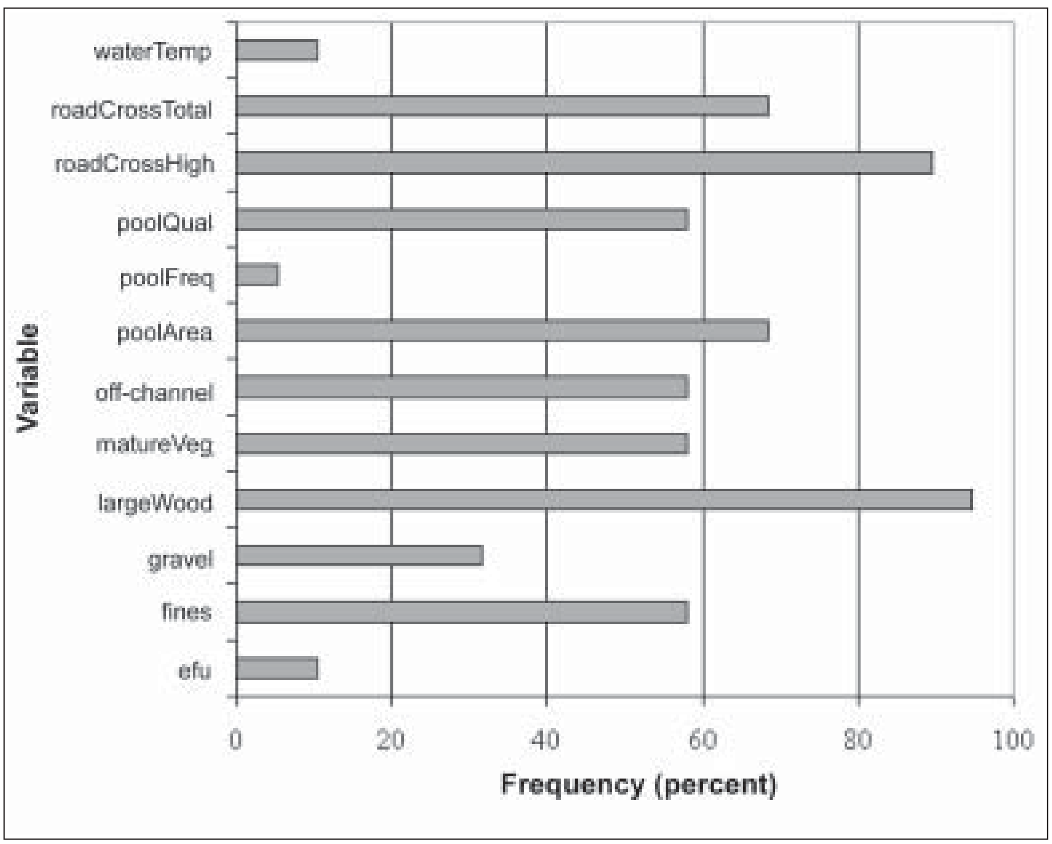

Figure 9—Frequency with which data in low-gradient drainages contributed to the conclusion of a compromised or degraded biophysical condition. Drainages with an average reach gradient less than or equal to 4 percent were classified as low gradient; data on in-channel conditions were available.

Performing Evaluations With Incomplete Information

It is probably fair to say that almost all significant monitoring and assessment programs start out with significant data gaps. The NetWeaver logic engine is particularly well suited for use in applications such as evaluation monitoring in particular and ecosystem analysis in general because it is able to reason with incomplete information and still provide meaningful results, and because it can evaluate the influence of missing information.

We noted earlier that the number of topics in any reasonably realistic problem and the number of interdependencies among them can easily overwhelm the capacity of the human brain to reason effectively about such questions as, What is the most useful information that I could acquire at this point in time to improve the completeness of my analysis? It is important to appreciate that the influence of information is highly dynamic: the influence of what is missing depends both on the observations that are currently available, and on the values in those observations. Consequently, use of iterative analysis of data influence in EMDS following successive, incremental additions of new data could conceivably reduce resources devoted to data collection on the order of 50 percent in typical applications.

In our very small example, the distributions of missing data (fig. 5) and data influence (fig. 6) mirror each other. More generally, and particularly for larger and more complex logic models, the two distributions may be very different owing to interdependencies among data elements. Even in this simple case, however, it is clear that missing data on water temperature are the largest source of uncertainty in the current analysis (fig. 6). It also is quite possible that if some of the missing water temperature observations were acquired, pool quality, fines, and farm use might no longer have nonzero influence.

Explanation of Monitoring Results

The ability to explain monitoring results to colleagues, line officers, interested publics, etc. is at least as important as the ability to perform an analysis in the first place. If the logic of underlying models cannot be presented in clear, unambiguous terms to such audiences, results will not be trusted. Powerful and sophisticated linear programming systems such as FORPLAN largely failed on this account.

Our experience to date with EMDS, and with its knowledge-base browser interface in particular, has been that the presentation of results from logic models is easy to grasp at an intuitive level so the results are accessible to broad audiences with only limited explanation. An analyst can easily run the browser interactively in front of an audience, navigating the structure of the evaluated knowledge base, and explaining the derivation of the logic as he or she goes. The earlier logic diagram (fig. 4) provides a good example. Composite watersheds (WS type = 1) are screened out of the analysis with a logic switch and remain in an undetermined logic state. For true watersheds, the right-hand path under the WS type logic switch is followed. Biophysical condition of a true watershed evaluates as suitable to the degree that there is suitable riparian vegetation and a suitable upland environment. A second logic switch checks whether the data for the watershed include an evaluation of in-channel conditions. If a low-gradient stream survey was performed (lowGradSurvey > 0), then the evaluation includes the upland, in-channel, and riparianVeg topics; otherwise the evaluation of biophysical condition only depends on the upland and riparianVeg topics. Each of the three topics, upland, in-channel, and riparianVeg, has its own logic specification (not shown).

Evaluation Within Larger Contexts

Almost all landscape analyses are performed within the context of some broader scale. Our knowledge base for evaluation of salmon habitat suitability is a prototype constructed for the specific context of the Oregon Coast Range. Consequently, it is unlikely that the current version is sufficiently general for application throughout the planning region of the Northwest Forest Plan, which encompasses the range of the northern spotted owl (*Strix occidentalis caurina*).

Fortunately, it is not difficult to generalize prototypes such as ours for broader applicability. In some cases, for example, it may be sufficient to replace hard-wired arguments with a calculated one that contains a more general fuzzy membership function whose parameters vary with additional context information. For more dramatic

Figure 10—An example of knowledge-based integration across spatial scales.

variations in logic structure, it may be necessary to add new logic switches that similarly select alternative logic pathways based on additional context information. In a technical sense, knowledge-base generalization is a relatively minor issue. On the other hand, it leads naturally to discussion of the more interesting question of multiscale implementations.

Extending Ecosystem Management Decision-Support Applications to Multiple Spatial Scales

It is relatively easy in principle to extend integrated analysis via knowledge-based reasoning over multiple spatial scales (fig. 10). Data from fine-scale landscape features such as 6^{th}-code watersheds are first processed by a knowledge base designed for that scale. Knowledge-base output, shown as evaluated states in the middle of the figure, then go through an intermediate filter (typically implemented in a spreadsheet or database application) to synthesize information for input to the next coarser scale. A second knowledge base processes the synthesized information to provide an assessment of landscape-level attributes at the top of the figure. Finally, knowledge-base outputs at the broader landscape scale may feed back to the fine scale as context information that influences evaluations at the fine scale. This simple conceptual model provides the basis for a formal logical specification of analyses that are consistent across scales. Hierarchies, or even networks, of knowledge-based analyses as suggested would be highly consonant with ecosystem theories concerning the hierarchical organization ecosystems.

English Equivalents

1 kilometer = 0.62 miles

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Seeing the Forest and the Trees: Visualizing Stand and Landscape Conditions

Robert J. McGaughey[1]

Introduction

The appearance of forested landscapes and individual stands after forest management activities is critical to public acceptance of these activities. Even with thorough planning, detailed site-specific analysis, and careful monitoring, many management activities will not be truly successful if the public views the resulting landscape as an eyesore. Unfortunately, many people judge the success or failure of management activities based on the visual impact of the activity to an otherwise "natural" landscape.

Forestry professionals have long used visualization techniques to address a variety of forest management problems. Prior to the advent of computerized methods, they used "artists' renditions" to communicate the effects of land management activities. Perspective sketches and scale models continue to help communicate the spatial arrangement and extent of management activities to the lay public. However, current management practices use more detailed silvicultural prescriptions involving small treatment areas scattered over larger landscapes and the removal or modification of specific stand components. In addition, treatment regimes are designed to achieve a desired condition over long timespans by using a series of treatments. Given the broad range of treatments considered and changes to stand conditions over time, it is difficult to produce traditional artists' renditions that reflect the expected condition accurately and with a minimum of artist-contributed bias. In addition, the time required to produce artists' renditions limits their use when depicting several alternative treatment strategies.

Foresters charged with selecting stands for treatment and designing silvicultural prescriptions often find it difficult to comprehend the complex spatial and temporal interactions that occur across landscapes. Traditional work methods involving fieldwork, maps, and aerial photographs provide enough information to assess individual treatments but may not provide adequate information to fully evaluate the cumulative impact of treatments or the impact of treatments implemented over time. Computer-based landscape simulations are a recognized tool for assessing the potential visual impact of land use decisions and management activities. Visualization tools that include a stand projection component or provide linkages to such models can simulate and depict stand and landscape changes over time. Such presentations help to communicate stand and landscape conditions and how these conditions change as a result of management activities, natural disturbances, and growth over time. During the treatment design process, visualizations depicting treatments within their landscape context provide important feedback. Such feedback can help resource specialists develop and implement better landscape management plans. Furthermore, visualizations help communicate management activities to other resource specialists and public stakeholders.

Overview of Visualization Techniques

Computerized visualization methods range from simple diagrams to complete virtual realities. Four methods, described in detail and compared in McGaughey (1998), are commonly used to produce visual representations of forest operations:

- Geometric modeling
- Video imaging
- Geometric video imaging
- Image draping

Geometric modeling methods build geometric models of individual components (ground surface, trees, other plants, and structures) and then assemble the component models to create a scene that represents a forest stand or landscape.

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Video imaging uses computer programs to modify scanned full-color video or photographic images to represent changes to stand and landscape conditions. To portray a wide range of landscape conditions, video-imaging techniques use a library of images that represent different forest conditions to replace portions of an original image.

A hybrid approach, called geometric video imaging by this author, combines geometric modeling and video-imaging techniques to produce realistic images that accurately represent data describing the effects of forest management activities. Operators use geometric modeling to produce images that specify the location, arrangement, and scale of stand or landscape features. These images then guide video-imaging manipulations that modify a photographic image to reflect proposed stand or landscape changes. By combining the precise spatial location capabilities of geometric modeling and the photo-manipulation capabilities of video imaging, hybrid methods result in spatially accurate, photo-quality images. However, hybrid techniques, like video imaging, require extensive libraries of tree and stand images to represent an appropriate range of species, tree sizes, growth forms, landscape positions, and treatment options.

Image draping mathematically "drapes" an image over a digital terrain model to create a textured surface. The draped image is typically a satellite scene, aerial photograph, orthophoto, or scanned map sheet.

Of the four methods, geometric modeling provides the most consistent link between data describing stand and landscape conditions and features in a generated image. In general, there is a one-to-one relationship between data elements and objects in the final image. Geometric modeling produces images that are generally less realistic than images produced from photographs. However, if photographic icons are used to represent individual trees and other objects, geometric modeling can produce images that contain many of the details normally associated with photographs.

Visualization of Stand/Plot-Scale Areas

Foresters use stand tables, showing the relative abundance of plant species and size classes, and simple graphs, showing single or multiple stand attributes as a function of stand age, to present information describing forest stands and stand conditions. These communication tools, suitable for conveying simple data relationships to scientific and professional audiences, do not always provide an easily understood representation of a forest stand or the changes in stand structure that can occur after disturbances or natural processes. The Stand Visualization System (SVS) was designed to help foresters understand and communicate stand conditions and changes in stand conditions resulting from management activities or natural processes (McGaughey 1997).

The SVS uses geometric modeling techniques to create images depicting stand conditions. As part of the stand construction process, SVS converts tables describing the population of standing trees, down material, and understory shrubs into a list of individual stand components, e.g., trees, down logs, and shrubs. Standing trees and down material are defined by using the number of trees or logs per hectare. Understory shrubs can be defined by using the number of plants per hectare but are more commonly defined by using a percentage of cover. The SVS generates enough plants to achieve the desired cover. Plant locations are generated by using a variety of spatial patterns including patterns that mimic natural and planted stands. The SVS also reads output from the Forest Vegetation Simulator (Wykoff et al. 1982) and ORGANON (Hester et al. 1989). The images produced by SVS, although abstract, provide a readily understood representation of stand conditions and help communicate silvicultural treatments and forest management alternatives to a variety of audiences. The SVS provides the following specific capabilities:

- Display overhead, profile, and perspective views of a stand.
- Differentiate between stand components by using different plant forms, colors, or other types of marking as specified by users.
- Provide tabular and graphical summaries of information represented in a stand image.
- Facilitate the design of silvicultural treatments by allowing users to select individual stand components and specify treatments.
- Display information describing individual stand components as they are selected by the user.

Once an SVS tree list has been created, users can simulate silvicultural treatments by selecting individual trees or groups of trees and specifying a treatment action such as removal or pruning. As an alternative, treatment rules such as "remove 75 percent of the stand basal area from below" can be applied to the entire stand. Figure 1 shows a 1-hectare stand before and after a simple thinning treatment that removes all of the alder (*Alnus* Hill.) trees and a portion of the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) trees. Figure 2 shows the same stand after a treatment that removed all of the alder and six small patches containing 30 percent of the Douglas-fir basal area.

Visualization of Landscape-Scale Areas

A wide array of techniques is available for presenting landscape-scale information ranging in complexity from simple tables and graphs to color-coded maps to photo-realistic computer visualizations. Computer visualization techniques are especially useful given the complexity of stand treatments, the spatial distribution of treatment units, and the desire to view landscape conditions over time. Landscape visualization provides the viewer with an easily identified image of a landscape complete with topographic features and stand conditions. A new visualization system being developed by the author, EnVision, is designed to portray landscape conditions by using data describing individual stands. EnVision provides several capabilities not previously available or not available in the same application. For example, EnVision can fill individual polygons with a texture derived from an aerial photograph while rendering individual trees in other polygons.

An EnVision scene is based on a gridded digital terrain model[2] that defines the ground surface. EnVision provides a variety of methods to represent the ground including gridlines and contour lines, with and without hidden area removal, and as a shaded, lighted surface. Surface features such as roads, streams, and points of interest can be represented as points, lines, or polygons on the ground surface or as solid walls or point markers sitting on the ground surface. To represent ground surface texture, EnVision can fill polygon features with textures derived from aerial photographs. This "synthetic aerial photo" capability can be used to provide ground texture representing vegetation under a canopy of larger trees that are drawn as geometric models.

EnVision can use a variety of data to describe conditions within individual stands. The simplest form of stand data consists of the distribution of tree sizes for each species present in a stand. More complex data include individual tree records from inventory plots that include species, diameter at breast height, total tree height, live crown ratio, crown width, and the number of trees per unit area represented by the record. Stand data are merged with data describing the growth form and general crown shape for each tree species to construct a geometric model for each tree in a stand.

Multiscale Visualization

The ability to visualize individual stands by using SVS has significantly enhanced a forester's ability to understand and communicate stand conditions and the effects of silvicultural treatments on a stand. Through linkages with the Forest Vegetation Simulator (Teck et al. 1996, Wykoff et al. 1982), SVS provides visualizations of stand growth and development. However, understanding the dynamics within an individual stand does not necessarily lead to a better understanding of the dynamics of an entire landscape. The complexity of landscape management plans, variety of stand treatments, and time period for which most plans are developed make it difficult to understand and communicate the plan's impact on the landscape. A system that links the design and visualization of individual stand treatments with the ability to display the stands within their landscape context is needed. EnVision provides this linkage by allowing the use of an SVS tree list to represent each stand on a landscape. In operation, EnVision replicates the SVS tree list to fill the stand polygon by

[2] Gridded digital terrain models that correspond to the U.S. Geologic Survey's 7.5-minute quadrangle series are available for most areas in the United States. Other terrain model types, e.g., TIN models, can be used to generate a gridded model by using geograpic information system (GIS) software.

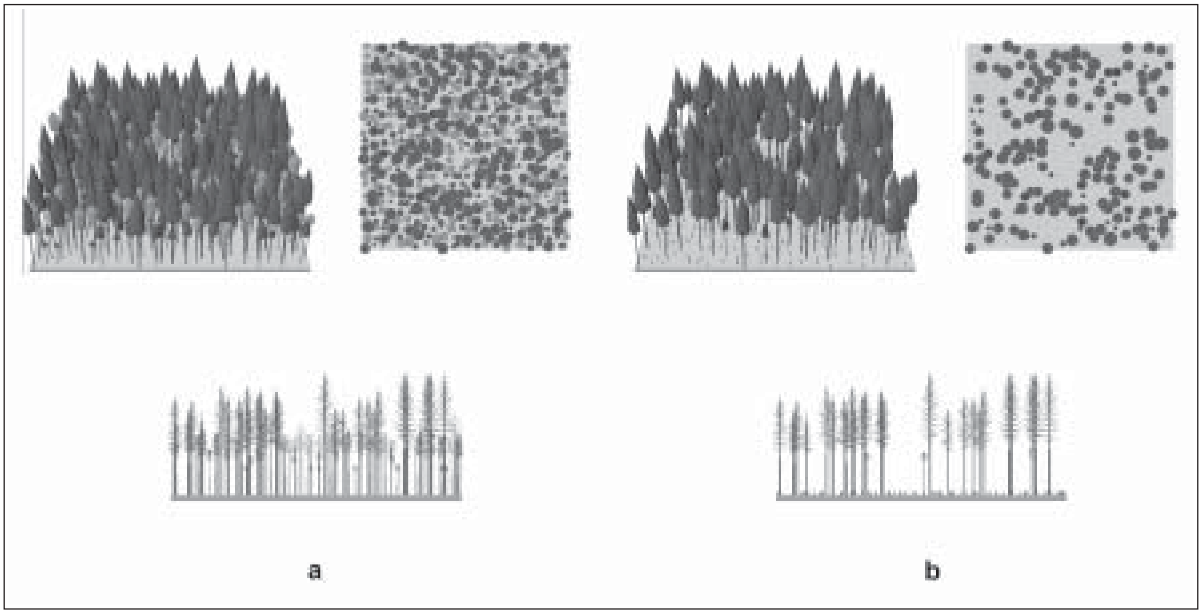

Figure 1—SVS visualization of a 1-hectare stand (a) before and (b) after a uniform thinning treatment. The thinning removed all of the alder and 25 percent of the Douglas-fir basal area from below.

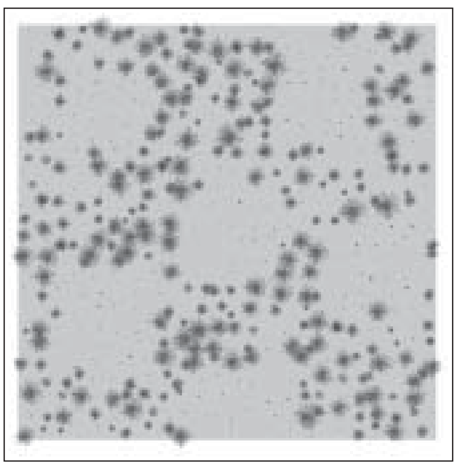

Figure 2—SVS visualization showing an overhead view of the stand shown in figure 1 but after a treatment that removed all of the alder and six small patches containing 30 percent of the Douglas-fir basal area.

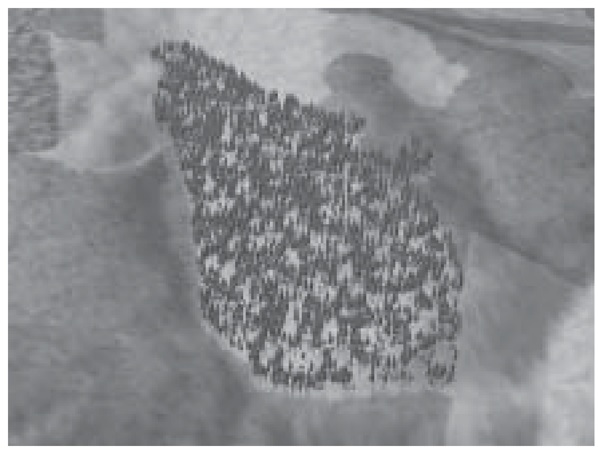

Figure 3—Landscape visualization produced by EnVision showing a stand polygon filled by using the SVS stand shown in figure 2. Individual trees have been rendered only in the polygon of interest. Other stand polygons have been filled with textures that represent the stand structure.

using a simple tiling algorithm. This linkage between SVS and EnVision makes it possible to design spatially explicit treatments within SVS and visualize that treatment within the landscape context. Figure 3 shows a landscape where the 1-hectare stand in figure 2 has been used to fill a 21-hectare stand polygon. In this example, SVS tile reflection has been used to minimize any pattern effects that might result when filling the stand polygon.

Conclusions

This paper has discussed a variety of techniques that can help land managers visualize, understand, and communicate stand- and landscape-scale management actions. In particular, this paper has highlighted the SVS and EnVision applications developed by the author.

Experience with SVS, UTOOLS/UVIEW landscape analysis and visualization system (Ager and McGaughey 1997), and Vantage Point prototype (Bergen et al. 1998) indicates that such visualization tools help resource specialists and land managers make better decisions. However, such tools also can produce photo-realistic images that can mislead viewers. Practitioners must be careful when using such tools that they do not intentionally or unintentionally misrepresent existing or expected conditions (Wilson and McGaughey 2000). Failure to do so will seriously limit the usefulness of these visualization techniques for future projects.

English Equivalents

1 hectare (ha) = 2.47 acres

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A Method to Simulate the Volume and Quality of Wood Produced Under an Ecologically Sustainable Landscape Management Plan

Glenn Christensen,[1] R. James Barbour,[2] and Stuart Johnston[3]

Abstract

Adopting the Northwest Forest Plan into federal land management brought with it many new challenges to forest planning. One challenge is to determine what effect using new and untested silvicultural treatments to meet ecologically based objectives will have on the production of wood or other products that society values. Determining the quantity and quality of potential outputs as a consequence of ecological restoration activities is important to helping understand the cost to society of implementing such a plan. The difficulty comes from the scale of the problem. No longer are short-term stand-level analyses adequate; evaluation of forest outputs has to be at meaningful spatial and temporal scales. To be successful, new methods will have to be developed.

The objective of this paper is to present a method used to evaluate wood removals from a landscape management plan that was developed to meet ecological objectives by mimicking past disturbance cycles. This required extending stand-level techniques for simulating quality and quantity of wood to 980 stands in the Blue River watershed of western Oregon. Silvicultural prescriptions include a range of thinning intensities and frequencies combined with extended rotation ages (100 to 260 years).

Study results include the range of products that might be manufactured under different silvicultural alternatives and evaluate the volume as well as the quality of primary and secondary products. Primary product quality estimates include log attributes such as diameter, branch size, juvenile wood, and growth ring count. Secondary product estimates include lumber or veneer volume recovered by grade and likely end use.

Introduction

Interest in the management of forests at the landscape level has increased dramatically over the past several decades. An area where this has recently received much attention is on lands managed by the USDA Forest Service in the Pacific Northwest. Prior approaches to forest management on these lands focused landscape-level planning on development of a road network to aid in wildfire suppression and dispersion of harvest activities. Stand treatments were primarily clearcuts designed to meet several objectives including rapid stand regeneration and the creation of edge and early seral wildlife habitat. Fueled by change in public perception of clearcuts and a growing concern over the effect of forest fragmentation on the loss of old-growth forest habitat on wildlife, especially the northern spotted owl (*Strix occidentalis caurina*), and water quality during the late 1980s, all Forest Service timber sales were temporarily suspended. To end the suspension, the Northwest Forest Plan (USDA and USDI 1994) was developed and is the guiding plan for 9.7 million ha of federally managed forest land.

The Northwest Forest Plan (NWFP) is based on a system of static reserves, riparian corridors, and general forest land called matrix lands. A criticism of the NWFP is the use of static reserves on a

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dynamic landscape. Recently, however, considerable interest has emerged as a different approach to landscape-level planning, and two studies have been initiated in the central Willamette National Forest of Oregon. Both the Augusta Creek study (Cissel et al. 1998) and the Blue River landscape plan (Cissel et al. 1999) have focused upon integrating historical disturbance regimes into landscape- and watershed-level management plans. These approaches use information on historical and current landscape conditions, disturbance history, and social goals to set objectives for future landscape structures that provide desired habitat, watershed, timber supply, and other functions (Cissel et al. 1999). The intent is not to mimic historical conditions but rather to use them as a reference in developing and evaluating management alternatives to meet these goals.

The Blue River landscape plan is an integrated landscape management strategy that was developed to achieve both ecological and social objectives. As stated in the plan, the "primary goal is to sustain native habitats, species, and ecological processes while providing sustained flow of wood fiber for conversion to wood products" (Cissel et al. 1999). The key underlying concept is that by simulating certain aspects of the historical fire regime through forest management activities, we can sustain the historical range of variability necessary to preserve these native habitats, species, and ecological processes while still providing a predictable flow of timber.

Regardless of which approach is used, methodologies and protocols are needed that describe the quantity, quality, and value of the wood produced under landscape-level plans. Managers also need to know when wood will be removed and from what locations on the landscape. In addition to difficulties from planning at large spatial and temporal scales, most modern forest management requires the use of complex silvicultural prescriptions in the form of thinnings, group selections, and individual tree selections to meet specific stand structure objectives. To address these complexities, the Landscape Management System (LMS) was developed at the University of Washington (McCarter 1997).

Study Area

The 23 900-ha Blue River watershed is almost entirely managed by the USDA Forest Service and includes the H.J. Andrews Experimental Forest, an area with an extensive history of ecosystem research. Of the 298 million ha of forest land within the United States, 19 percent (56 million ha) is managed by the USDA Forest Service (Smith et al. 1994). The Blue River watershed is located in the Willamette National Forest within the McKenzie River watershed, a tributary of the Willamette River in western Oregon (fig. 1).

The landscape is steep, highly dissected volcanic terrain of the Cascade Range. Annual precipitation exceeds 2500 mm falling mostly in October through April as rain at lower elevations and snow in higher areas. The landscape ranges from 317 to 1639 m in elevation and is covered largely by coniferous forests dominated by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and Pacific silver fir (*Abies amabilis* Dougl. ex Forbes) (Cissel et al. 1999).

Approach

The approach for this analysis is to use the Blue River landscape plan as the basis to determine scheduling of stand treatments and silvicultural prescriptions. The analysis focuses on wood production as trees are harvested to meet broader ecological objectives. The main tool used for simulation is the LMS, a computerized system that integrates landscape-level spatial information, stand-level inventory data, and distance-independent individual tree growth models to project changes though time across forested landscapes (McCarter 1997). Once current conditions are determined for each stand as accurately as possible, silvicultural treatments are scheduled and growth projections made. As stands are grown and treatments made, information is collected on individual tree volume and quality characteristics.

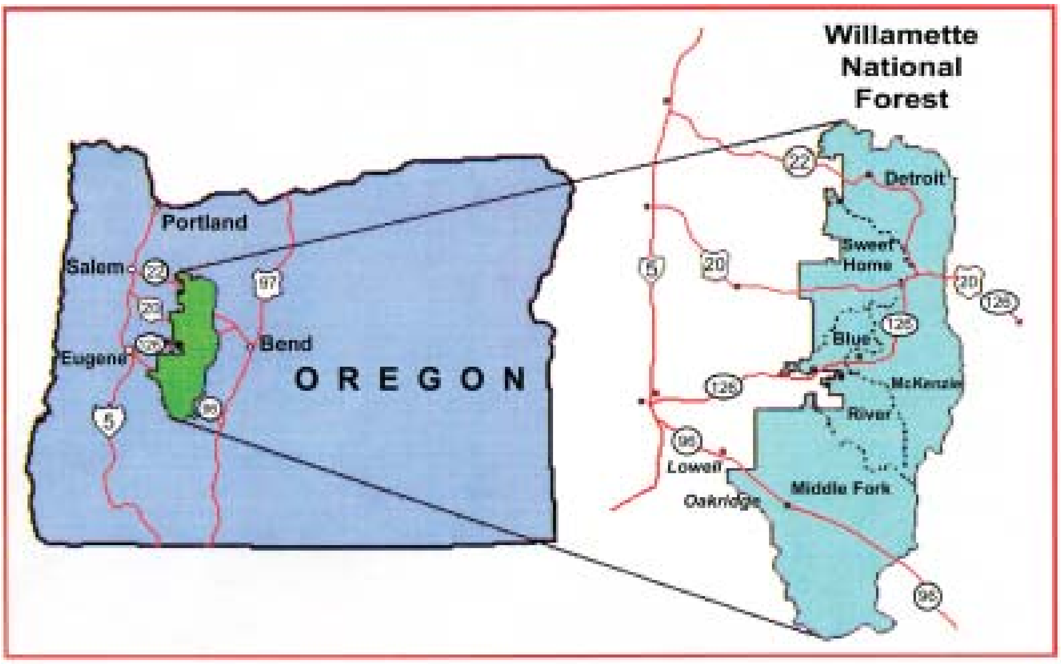

Figure 1—Location of Blue River watershed.

This analysis uses methods similar to those developed by Christensen (1997) and Barbour et al. (1996) to evaluate the volume and quality of wood from a range of silvicultural regimes. Tree volume and quality information is analyzed with the TREEVAL (Briggs 1989, Sachet et al. 1989) model to estimate potential lumber volume and grade recovery. The TREEVAL model was developed by the USDA Forest Service, Pacific Northwest Research Station to provide financial information and analysis of product recovery to support silvicultural decisions in coast Douglas-fir (*P. menziesii* var. *menziesii*). Analyses conducted by Christensen (1997) and Barbour et al. (1996) are temporally explicit, evaluating wood produced from individual stands through time. They are spatially implicit in terms of where the wood came from. The current analysis adds the spatial dimension to this process, providing not just wood production information as a stand develops over time, but also providing information on the source of wood from across many stands within a watershed. This gives planners the ability to understand how stand treatments will interact to provide a predictable flow of wood in terms of volume and grade recovery from a defined landscape.

Modeling Wood Production by Using the Landscape Management System

The LMS model was chosen for its landscape-level analysis capabilities, as well as its integration of various component programs to provide detailed tree volume and wood quality information. Of particular interest is the ability to choose among several different growth and yield models within the program to allow maximum flexibility in the number of species, kinds of silvicultural treatments, and output produced. Included in LMS are stand- and landscape-level visualization programs that permit, in addition to traditional quantitative analysis, generalized visual representations of different management options.

A detailed description of the methodology for each part of the project can be found in Christensen et al.[4] For this paper, a brief overview is provided giving the basic approach used during each phase of the study.

[4] Christensen, G.A.; Stuart, J.; Malinick, T.E. [In preparation]. Simulating the volume and quality of wood produced under an ecologically sustainable landscape management plan in the Oregon Cascade Range: results from the Blue River Landscape Plan. Res. Pap. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Current Stand Conditions

As part of the analysis for the Blue River Landscape Plan, much basic information had already been assembled. The most important of this information was geographic information system (GIS) data files. From the GIS data, we knew the stand type, vegetation association, and how the stand is to be managed. Now we needed an inventory for each stand with specific tree measurements. The LMS software requires specific stand inventory data including stand or polygon number, species, diameter at breast height, height, crown ratio, and expansion factor, on a per-acre basis. The spatial data requirements vary depending upon the growth-and-yield model selected but can include, by stand or polygon number, number of plots, regional location, site index, habitat type, age, slope, aspect, and elevation. Among the available data sets, it was determined that the inventory plots maintained by the current vegetation survey (CVS) in the Willamette National Forest had the most applicable stand inventories in addition to providing the most widely distributed sample plots.

By using CVS data for stand inventories we were able to determine current vegetation condition for many stands. However, a significant number of stands remained that had no available tree-level data. To overcome this, we used all available information to assign inventory data to these stands. By using a combination of vegetation association, stand type (tree species and structure), age, elevation, slope, aspect, and site index we were able to select the closest match from stands that had inventory data. Once this process was complete, we had an intact inventory for 980 stands giving us the current vegetation condition of the entire watershed.

Silvicultural Prescriptions, Stand Treatment Scheduling, and Growth Projections

As part of the Blue River Landscape Plan, the watershed was divided into two basic management categories, reserves and landscape areas. Reserves were established to protect special interest areas such as late-successional spotted owl habitat and riparian areas along fish-bearing streams. Landscape areas are the areas designed to meet a variety of ecological and social objectives where some level of timber harvest will occur (fig. 2).

For this study, reserve areas were assumed to receive no timber harvest and are not included in the analysis. Landscape areas were divided into three types based on interpretation of historical fire-return intervals and intensity. The three landscape areas are (Cissel et al. 1999):

- Landscape area 1–Frequent fire-return interval and moderate severity (40 to 60 percent mortality).
- Landscape area 2–Moderate fire-return interval and moderate-to-high severity (60 to 80 percent mortality).
- Landscape area 3–Infrequent fire-return interval and high severity (>80 percent mortality).

Cissel et al. (1999) developed silvicultural prescriptions for each landscape area to closely mimic natural stand development following a fire (table 1). Treatments were designed to produce stand structures and wildlife habitat closely resembling historical conditions within the watershed. These prescriptions were used in the LMS model for this analysis. It is assumed that for each prescription, reforestation (through replanting) will succeed under some level of overstory. It is also assumed that, as after a natural fire, overstory retention will be nonuniform and distributed as patches and scattered individual trees throughout the stand. Patchy overstory retention also will stimulate understory growth in the gaps aiding replanting success and development of vertical structural diversity. Further structural diversity, both horizontal and vertical, will be developed through several thinning entries prescribed for each landscape area.

Simulation of stand growth within LMS used the ORGANON growth and yield model (Hann et al. 1994). ORGANON has the advantage of allowing detailed silvicultural treatments and provides quantitative estimates of important stand attributes such as percentage of crown cover following a thinning. Another advantage of ORGANON is that it provides estimates of tree quality characteristics as an optional output. Tree characteristics estimated by ORGANON include height to each branch, largest branch diameter, diameter of the juvenile wood core at each branch whorl, and diameter inside bark of the stem at each branch whorl. A similar output from LMS has been developed but has not been fully tested. A limitation of

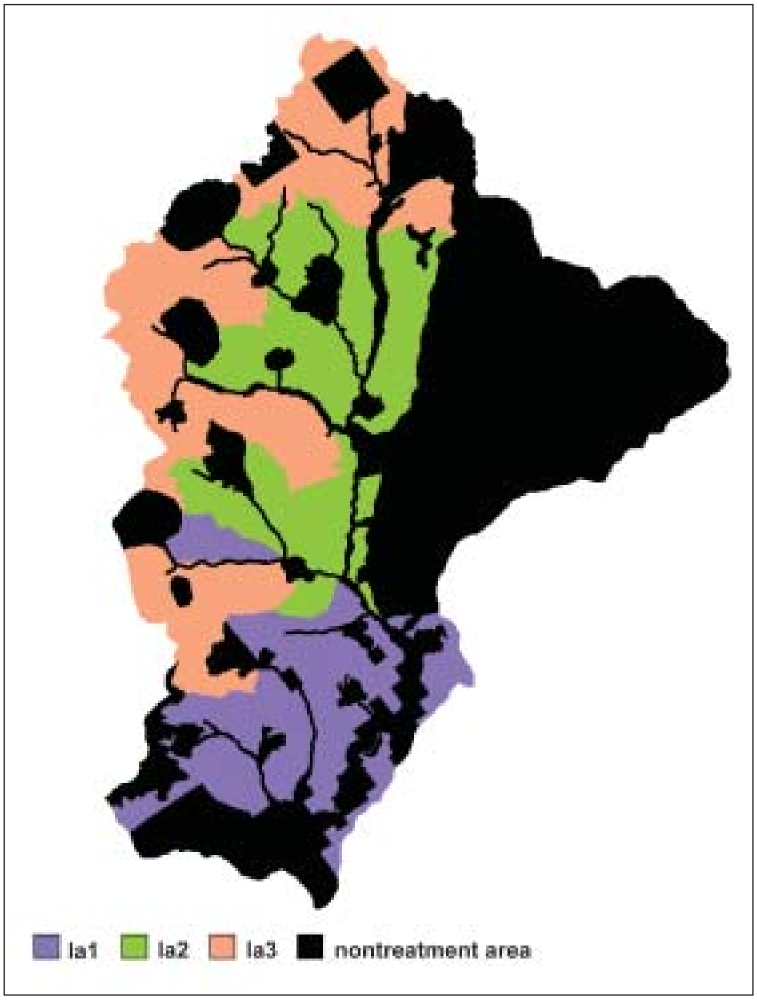

Figure 2—Blue River Landscape Plan treatment areas (Cissel et al. 1999).

Table 1—Blue River silvicultural prescriptions

Prescription elements	Landscape area 1	Landscape area 2	Landscape area 3
Rotation age (years)/% regeneration harvested annually	100/1.0	180/0.56	260/0.38
Landscape block sizes			
<40 ha (% of area)	60	20	20
40-80 ha (% of area)	20	40	40
80-160 ha (% of area)	20	20	40
Retention level (% of existing overstory crown closure)	50	30	15
Retention mixture (% of species dependent on plant association)	Shade intolerant – 65 Shade tolerant– 35	Shade intolerant – 80 Shade tolerant– 20	Shade intolerant – 95 Shade tolerant– 5
Reforestation density (trees per hectare)	500	750	1000
Reforestation mixture (% of species dependent on plant association)	Shade intolerant– 40 Shade tolerant– 60	Shade intolerant– 60 Shade tolerant– 40	Shade intolerant– 75 Shade intolerant– 25
First thinning (tph)[a]	500 at year 35	500 at year 20 to 25	500 at year 12 to 15
Second thinning (tph)	250 at year 35	275 at year 40	275 at year 40
Third thinning (tph)	150 at year 65	200 at year 70	200 at year 60
Fourth thinning (tph)	Not planned	125 at year 100	125 at year 100
Low-severity fire (in addition to fuel treatments)	Not planned	Once between years 100 and 180	Twice between years 100 and 260

[a]Tph = trees per hectare.

Source: Cissel et al. 1999.

growth models is the inability to simulate patches and gaps within a stand. To accurately estimate the effect of these treatments on tree growth and quality, models will need to have this failing corrected. Currently the best we can do is to use spatially uniform stand treatments and assume the effect on overall stand growth and quality is negligible.

A key part of the Blue River Landscape Pan is when and where stand treatments occur. To move away from further forest fragmentation, Cissel et al. (1999) applied treatments to areas designated as landscape blocks. An individual block ranges in size from about 40 to 160 ha and may contain several stands. Harvest entries were scheduled with an area-control approach by using the landscape block as the basic unit. Blocks were designated for entry in 20-year periods over 200 years. Scheduling of harvest entries in LMS is accomplished through a scenario file that contains the year of treatment, stand number, and treatment description. By using this file, silvicultural treatments can be programmed for multiple stands across the entire landscape through time. Despite being able to simulate the growth of many stands for a large area, the current model cannot simulate interactions among stands.

Analysis of Wood Volume and Quality

Analysis of wood production is completed after stands have been grown and silvicultural treatments applied by using the LMS model. LMS can be configured to simulate bucking of trees into user-defined log lengths. Currently, logs can be defined by only diameter and length, but work is being completed that incorporates additional quality characteristics such as number of branches, branch diameter, growth ring count, and diameter of juvenile wood core. For this study we focused on lumber production from each regime and differences in tree characteristics. Tree-quality characteristics are summarized for each regime from information in the ORGANON wood quality output file. To simulate lumber production, the TREEVAL model is used. TREEVAL is designed to accept ORGANON wood-quality output files as input. TREEVAL calculates financial information allowing comparisons of different silvicultural regimes. For this study we were interested primarily in the volume and quality of lumber recovered for each regime. Lumber recovery equations from Fahey et al. (1991) have been programmed into the model estimating yields of veneer and lumber. Lumber recovery can be combined for visually graded and machine-stress rated (MSR) lumber. TREEVAL simulates the bucking of trees to a nominal log length of 4.9 m and a minimum small-end diameter of 13 cm. Volumetric lumber grade recoveries were estimated for each log by using the TREEVAL model.

Conclusion

For this paper, we wanted to demonstrate that by linking existing simulation models, a detailed analysis can be made from a landscape-scale perspective of wood volume and quality from many individual stands. This information can be used to evaluate wood removals based on different approaches to planning on a large scale. Timber production comes from tree removals as part of stand treatments used to develop specific structural attributes through time. All approaches have an eventual rotation age that is longer than that used in traditional management for timber production. The combination of using unique stand treatments with long rotations will have an effect on the volume and quality of wood available for commodity production. It is unknown what the magnitude of this effect will be, and simulation models give us an opportunity to look at potential trends.

English Equivalents

1 hectare (ha) = 2.47 acres

1 millimeter (mm) = 0.039 inches

1 centimeter (cm) = 0.39 inches

1 meter (m) = 3.28 feet

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Transforming Information From Many Perspectives to Action on the Ground

A Social Science Perspective on the Importance of Scale

Linda E. Kruger[1]

> All ecological processes and types of ecological structure are multiscaled. Each particular structure relates to a particular scale used to observe it such that, at the scale of perception, the entity appears most cohesive, explicable, and predictable. The scale of a process becomes fixed only once the associated scaled structures are prescribed and set in their scaled context. **Scaling is done by the observer; it is not a matter of nature independent of observation.** (Allen and Hoekstra 1992: 11, emphasis added.)

This paper offers a very brief introduction to some scale-related considerations from the perspective of a social scientist. The paper does not provide an indepth discussion, but my hope is that enough information is provided to provoke thought and additional exploration in these areas.

Scale and the Human Frame of Reference

As Allen and Hoekstra (1992), among others, have noted, scale is a social construction. This means that scale is not something that is out there on the ground that exists apart from humans but rather it is something we create by assigning defining attributes to it. A particular scale does not exist in reality and has no meaning until we give it meaning (Tuan 1974). Thus, those who select a particular scale have a responsibility to clarify its meaning to others.

In addition, scale only has meaning relative to the human frame of reference. Recall the relation Gulliver had to the lands and people he visited. The differences in scale that he experienced were all relative to his own size and personal past experience. Because each of us brings a different past experience with us, we will see the same things differently. This means that we need to look at places and projects together so we can share with each other what each of us "sees" rather than assuming we are all seeing and experiencing a place in the same way.

Most of us (as humans) experience places at the scale of a site–a place we go fishing, camping, or hiking, for example. Some of us may experience a sense of place or special attachment to certain places, usually at small scales. However, when asked to comment on a forest plan at the scale of a national forest, many of us (as citizens) may be at a loss as to how to express how we feel about those special places. Thus, both agency planning processes and research questions need to recognize the interconnectedness across multiple scales and scale down to smaller scales so that citizens can better understand the implications of a decision or finding on "their place." Often the boundaries identified for purposes such as planning and research are not socially significant or meaningful to citizens.

Nassauer (1997) suggests that landscape scale does not have a universal definition. She identifies two common uses of the concept:

> (1) a heterogeneous combination of ecosystems, which affect each other across space and time, and (2) a "middle" scale, within a hierarchy, of ecological processes that affects smaller-scale processes and is affected by larger-scale processes. Both the concepts of heterogeneity and hierarchy emphasize the connectedness of the landscape across space and time. Connectedness, then, is an essential property of the landscape scale. (Nassauer 1997: 73)

Nassauer (1997: 73) goes on to suggest that "at the scale of human beings, connectedness refers to landscape structure that allows flows of water, nutrients, energy or species that people have noticed and believe to have ecological value."

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From this perspective, landscape scale is a cultural concept based on what we determine to have value. Because we as humans manage landscapes, we often arrive at a definition of landscape scale by identifying what we perceive as management units (Nassauer 1997). Based on this perspective, landscape scale could mean someone's backyard, a watershed, ranger district, or national forest. "In each case, the ecological functions of individual patches of lakes, streams, turf, fields, forests, or even pavement are connected to one another" (Nassauer 1997: 73). Thus, landscape as a scale of analysis is similar to the social concept of community in that landscapes, like communities, are nested and embedded in each other at various scales, rather than representing one specific scale.

It is this connectedness of ecological functions across space that makes working across landscapes essential. However, working across landscapes is often easier said than done. Patchwork ownership patterns put landscape-level decisions in conflict with our culture's belief in private property rights. More work is needed to develop tools and incentives for working across boundaries in ways that minimize the threat to people's sense of private property rights. (See Kalinowski's [1996] discussion of Leopold's land ethic, specifically his differentiation between land as property and land as territory.)

The ability to take a cross-boundary perspective—looking across management jurisdictions, ownerships, and administrative and legal boundaries—expands the possibility of considering questions at the appropriate scale (Knight and Landres 1998). Like scale, boundaries are created by society for a variety of social purposes. Boundaries organize space. They often cut across other social relations that define space. For example, the city I live in lies within a school district that includes two other cities. It is bisected by a county line. Boundaries define to whom we pay taxes, for whom we can vote, and who will represent us in government, where our kids go to school, where our water comes from, and in some parts of the world even where people can and cannot travel. Creating boundaries is a process of place-making or constructing an identity that differentiates what and who are inside the boundary from what and who are outside the boundary.

Determining appropriate planning or study boundaries is important. Just as important is keeping in mind that boundaries are always porous and open across time and space (Massey 1995). The identities of places are products of links to other times and places. Although each place is unique, its interconnections to other times and places are important in defining its uniqueness.

Appropriate Scale

Scale is an important consideration for both managers and scientists. Every resource issue and question has a spatial and temporal component or context. In choosing the appropriate scale, we must consider at what scale our knowledge is reliable and at what scale we are most comfortable making predictions (Haskell et al. 1992). What the appropriate scale is depends on the question(s) being asked and can range from a small personal space (How will this plant look on my desk?) to the entire earth (How might this activity influence global change?). For social inquiry the most common scales are community, county, state, and region. Counties are frequently used for analysis because they are a major unit used by the USDC Bureau of the Census. Machlis et al. (1995) participated in the social assessment process portion of the Interior Columbia Basin Ecosystem Management Project (ICBEMP). They suggest the county as the best scale for social analysis, noting that data are readily available and that counties are increasingly involved in resource policy through planning and zoning activities. They also suggest that the county scale fits best with landscape-level analysis (Machlis et al. 1995: 13-16).

Although there are advantages to the county scale and major studies such as ICBEMP and Forest Ecosystem Management Assessment Team (FEMAT) do not support higher resolution community-level studies, there also are limitations to working at the county scale. The effects of resource decisions are often felt at the local level, and communities within a county can differ dramatically, particularly in a county that has a mix of urban and rural areas. Working at the larger, county-level scale also tends to disenfranchise people whose interests are more local. These are often the people who will feel a study "has been done to them." It also can be hard to make county-level data meaningful to a community. As a society, we need to explore methodologies that enable people to learn about themselves and their places at a variety of scales that are meaningful to them.

The ability to consider a question at the appropriate scale may be constrained by a variety of factors including the scale at which data are available, time or funding, political considerations, logistical problems, and project location (Committee on the Applications of Ecological Theory to Environmental Problems 1986). In many cases, ownership, management jurisdiction, or another administrative or legal constraint instead of the question or issue itself determines the spatial area that is considered.

Working across disciplines or multiple types of information may require synthesizing finer scale information to a coarser scale common with others. For example, socioeconomic data may be available only at the county scale, whereas biophysical data may be available at a combination of scales including the watershed, stream reach, stand, or province. The identification of a cross-cutting question may be a helpful first step in identifying an appropriate scale at which to integrate across disciplines.

The Committee on the Applications of Ecological Theory to Environmental Problems (1986: 97) determined that a "fundamental problem in predicting and controlling cumulative effects is the frequently large mismatch between the scales or jurisdictional boundaries of management authority and the scales of the ecological phenomena involved or their effects." The committee notes that an affected environment often crosses several jurisdictions. In addition the impacts of an action may be felt in a different jurisdiction far from where the offending action took place.

Thus, the scale that is chosen must be large enough to encompass interactions, larger scale processes, and cumulative effects (over time and space) without losing sight of important details, smaller scale processes, and interactions. At broader scales, important variability can be masked; at narrower scales important effects, levels, and nature of impacts can be missed; and at scales that are mismatched, it can be impossible to develop linkages between human communities and forests.

Considerations in Choosing a Particular Scale

In choosing a particular scale to use when designing a study or planning area, asking the following questions may be helpful.

- What assumptions underlie the choice of this scale? Are these reasonable assumptions?
- What is the justification for choosing this scale over others?
- What is being overlooking or ruled out by choosing this scale over others? Are we missing any critical questions?
- Are we choosing a particular scale because we have data available or because measurement is easier than at other scales?
- What are the implications of working at this scale?
- Does our choice of scale match our objectives?

How does the choice of a particular scale affect ecosystem management efforts? In an attempt to begin to address this issue, Norton (1992) identifies four ways in which scale affects ecosystem management.

1. Spatial boundary issues. Jurisdictional boundaries usually do not correspond to natural features or biogeography.
2. Temporal perspective. Biological (and social) systems are dynamic. Thus managers may have to decide whether to manage for current social values, production of "essential services," or features that are critical to maintaining natural processes.
3. Organizational structure and scale. This aspect of scale has to do with substructure. Once a whole system is defined, subunits, each with their own boundaries, must be identified. Taking an example from social science, a nation may be made of states, which might be subdivided into counties, which have within them cities and towns and neighborhoods where families and individuals live.

4. Scale and degree of impact. The degree of impact an action may have on a system depends both on the scale of the activity and the scale of the system. Activities that might degrade a small site might have negligible effect at a larger scale. As the scale of the activity increases, it might have higher degrees of impact at ever increasing system scales. Often the effects of our actions have impacts at a variety of scales.

So what happens if our choice of scale is less than optimal? There are several possible outcomes of analysis or action at the wrong scale. The following are drawn from the Committee on the Applications of Ecological Theory to Environmental Problems report *Ecological Knowledge and Environmental Problem-Solving* (1986).

1. Well-intended efforts can have minimal or even adverse effects if planned for too short a timeframe or too small an area.
2. Key processes might be overlooked at larger temporal or spatial scales.
3. Averaging over larger areas can mask the importance of processes at smaller scales because it is more difficult to detect subtle differences.

In addition to these concerns, a focus on single actions at whatever scale can result in obscuring cumulative effects over time and space. Cumulative effects can take several forms ranging from activities that add materials to the environment, such as discharging effluents, to those that remove materials from the environment, such as harvesting timber. Cumulative effects can take the form of changes over large areas for long periods of time that result from management actions, such as when a forest is managed based on single stands. Cumulative effects also occur when several actions compound each other; for example, when logging roads are built, logging, recreation, hunting, poaching, and other activities increase and affect a variety of forest species. The importance of understanding and considering the implications of cumulative effects makes a strong case for the consideration of multiple spatial and temporal scales.

The Inclusion of Citizens in Planning and Decisionmaking

Transforming information into implementation on the ground requires both recognition that humans are part of ecosystems (rather than an outside force) and the inclusion of citizens in planning and implementation. This requires us to shift our thinking from "unfortunately we have to work with people" to "citizens are critical to an informed, effective process." Collaborative planning, when used in Forest Service planning processes, requires participation of researchers, managers, and citizens. It recognizes that citizens have knowledge and real world experiences to contribute to the planning process. Frequently citizens also bring a passion for action, and citizen participation can result in better decisions and an improved process. Land managers can share responsibility for environmental quality and health with those outside the agency only if they provide opportunities that include citizens as meaningful participants in planning and decisionmaking processes.

It also requires an understanding of the various scales at which people identify a landscape as a place that they relate to. Geographer Gillian Rose (1995) suggests that people develop a sense of belonging or connection to places at multiple scales including a local scale, a regional scale, a national scale, a supranational scale, like Europe, and even at a global scale, as our social and economic systems become more globalized. This means that as managers consider who should be involved in local planning processes, they must think beyond the local geographic community.

"What kinds of evidence, scientific or otherwise, are necessary to justify a given choice regarding the scale on which environmental problems are addressed?" Norton (1992: 35) answers his own question by suggesting an interdisciplinary approach that acknowledges that questions of scale involve value judgments. "The correct scale on which to address a management problem is determined by what society wants to accomplish with that system" (Norton 1992: 36). Norton joins others in suggesting that citizen involvement in dialogue and debate is necessary in order to facilitate consideration of alternative actions and desired conditions.

Scale may influence citizen involvement in management and planning. It can be much more difficult for citizens to comment on large-scale proposals that are not linked to specific small-scale places they can personally identify with. Forest plans are at a scale many citizens find difficult to respond to. We might speculate that watersheds, especially at the local community level, are a more meaningful scale as evidenced by the number of grassroots watershed groups.

Frequently, federal land management agencies conduct planning processes at the scale of a national forest. Ecosystem management is based on planning at a large scale, often including areas larger than a national forest. The FEMAT and the ICBEMP each covered several states. At these broad scales it is easy for people and their interests and concerns to get lost.

How meaningful public participation can be is often a function of the scale at which a study is initiated. The scale or scope of a place being studied is important in the sense that it has to be a scale that people can relate to. What is important is that the scale is appropriate to the question or issue being addressed and that it does not obscure what is meaningful and what people can relate to.

We must also take care that the tools and techniques that we use do not obscure what it is that is meaningful and important to people. Technology has provided us with tools that enable us to create pictures of what a stand or landscape will look like immediately after harvest and at intervals thereafter. In addition to its use in presenting information, this technology is often used to solicit public response to harvest practices (Shindler et al. 1995). Although the technology can serve a useful purpose in helping citizens visualize what the land will look like over time as the forest greens up, some researchers have concerns with its use in measuring public judgments of acceptability.

Studies have found that judgments of acceptability of management practices are based on more than just looking at a scene and responding to what is there (Brunson 1993, Shindler and Cramer 1999). Research done by some of our collaborators has identified a number of factors that play a role in the acceptability of resource management decisions and actions. For example, the respondents' personal experiences both with the specific place and the agency proposing the activity and their level of trust in the agency often play a role. A sense that "too much has already been cut" or general concerns over wildlife, recreation, or scenic values also may play important roles. Finally, how the decisionmaking process is carried out is important to some people. If people feel they didn't have opportunities for meaningful participation or if they didn't feel heard, they may object to an activity regardless of how the project looks on the ground. I think a quote from the child's story, *A Little Prince* (Saint-Exupery 1943: 87) aptly describes this situation: "What is essential is invisible to the eye." What is essential to understanding how acceptable a forest practice is may have less to do with how the forest appears and more to do with aspects of how and why it looks the way it does and where it is located relative to places people care about.

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Conclusion

Summary Remarks on Views From the Ridge

T.F.H. Allen[1]

I was asked not to prepare remarks ahead of the workshop, but rather to respond to what I saw and heard. Let me say at the outset, I have been much impressed with the general thrust of this workshop. Many of the papers were technical and represented sound research, but the real strength of the presentations as a whole was in the genuine eagerness in tackling big problems. The big problem, as I see it, is that we have many large-scale problems with regard to renewable resources, and that there is a huge divide between how science prefers to work and what needs to be done. We should be impressed with the high level of appreciation for the difficulties, and the vigor of the response in so many of the presentations. I saw courage in the presenters I heard.

As an example, we are really quite good at quantifying arcane models about cutting regimes. But what is the use of this to the end consumer of these results? The models mean nothing until we visualize the landscape in images that anyone can see and understand. I saw exactly that at this workshop. The new gigabytes and gigahertz of computer capability are powerful, because they let us translate abstractions, such as a 10-percent cut, into an image that the public can see and evaluate. New technology really does change the game, as we fly down streams and summarize their condition with thermal imagery. The problems are large, but the new technology moves human achievements upscale to meet many of them. Even the papers that used no technological "fancyware," were generally very cognizant of the need to serve the interface between humans on the landscape and the biogeophysical landscape itself. When we manage an ecosystem, we do not manage the material ecological system itself; rather we manage the presence of the people who impact the system. And that does not mean we manipulate the public covertly or dishonestly. No. Ecosystem management will not work unless it involves explicitly giving people options that they are prepared to use, and a sound basis to select among them.

What I have described above is what Silvio Funtowicz and Jerry Ravetz call postnormal science (Ravetz 1999). Although normal, merely modern science is meticulous as it tries to approach reality with its models; the postnormal scientist cannot afford to be so idealistic. Postnormal situations are characterized by (1) high stakes, (2) insufficient data, and (3) a short time fuse. The data from normal science will not be coming in time, for the issue will have passed, win or lose, before meticulous experiments and confidence limits can be achieved. Even so, scientists must offer their best advice anyway, and the manager must act on that best advice. Clearly finding out what is the reality of the situation is irrelevant, but, if it is any comfort, reality was never achievable anyway.

Beyond postnormal science is postmodern science. In the classical world and modern world the novice became dexterous, and the apprentice became a craftsman, while the master went beyond all to create something in a new framework. The novice and apprentice achieve quality by being meticulous, delivering exactly what is needed every time. That is called structural quality. The master introduces a different quality, a dynamical quality of good change, which itself undermines the premises that underlie structural quality. Quality classical work was approved by common standards, where the external consensus was that everyone liked the picture of the Patron. The difference between classical and modern is that in the modern world, external reality becomes the external reference. Elites, be they cubist painters or 20th-century scientists, assert that by looking at the world their special way, ultimate reality may be approached. But in a postmodern world there is no external reference, be it consensus or reality. In postmodernity, it is not that it is all in our heads and anything goes, it is rather that we only deal with data, not with ob-

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jective reality. Without an external reference, the postmodern scientist must make the process of science justify itself, but how? The answer is that we need to keep science a high-quality activity in both structural and dynamic features. Even though we cannot now pretend that science is objective, it is quality that is endogenous to doing science that continues to give science its deserved privileged position (Funtowicz and Ravetz 1992). Science is meticulous so it can repeat anything it does, and that amounts to structural quality. Science also challenges its products at every level from the null hypothesis all the way to fighting over new paradigms. That is dynamical quality.

Structural and dynamical quality, that is, honest carefulness and creativity, make science the best game in town. And we saw lots of both sorts of quality at this workshop. Some papers were technical and were splendid displays of structural quality. Other papers were full of dynamical quality, as managers, politicians, scientists, and the lay public made visionary statements of what to do next, as we reach out to a world full of people with values living in systems that are the purview of the Forest Service.

It is good to see such courage and commitment to dealing with the values of people in the biosphere, because the problems are huge. Joseph A. Tainter (1988), of the Rocky Mountain Research Station, points out that societies are problem-solving units that elaborate processes or approaches to deal with resource issues. It appears inevitable that problem solving proceeds to greater cost and less benefit with vicious diminishing returns. Eventually societies lose either the political will or the ability to deal with the last problem, whatever form it may take, and the people just walk away from civilization.

Some societies on the edge of collapse find a new lease on life by switching to some fundamentally new resource, such as coal when Britain ran out of wood. Looking at attoid ants, we see that the primitive species farms fungi on grasshopper droppings, which amounts to jet fuel for growing fungi. The problem is that insect droppings are a highly processed, scarce material, albeit of high quality. Leaf-cutting ants have evolved further to use leaves instead of guano, and so overcome the scarcity issue. But leaves are a low-quality resource, and so demand very organized processing. Diminishing returns on a high-quality resource, such as guano, end in collapse when the supply runs out. Diminishing returns on a low-quality resource, such as leaves, end in collapse when the huge system grows into excessive demand. Counterintuitively, more capital is built on diffuse, low-quality resources than on high-quality resources.

It appears that human society often switches from high-quality resources (HQR) to low-quality resources (LQR) in cycles of elaboration. The energetically easy entry to a general type of resource is on HQR, and the elaboration upscale is on LQR. Thus (1) hunting (HQR) leads to (2) agriculture (LQR). In an agricultural setting, (3) looting neighbors (HQR) gives way to (4) imperial taxation of peasants (LQR). In the First World we live on (5) industrialization (HQR). Without meaning to describe any sort of grand historical narrative, we note that some political arrangements collapsed at various stages, e.g., Mongols in the West at step 3, or the Romans at step 4.

We look as if we are about to come off the back side of step 5, fossil carbon, and need a new LQR phase. Because renewable energy sources are all low quality, they will have to be extensively captured, rather like sun on crops. Much more ecological damage has been done by LQR agriculture compared to HQR fossil fuels. The change to the LQR hydrogen economy using wave, wind, biomass, and solar energy may be wrenching, as human settlement decentralizes. The diffuse nature of high-technology information systems allows for energy self-sufficient production systems scattered across the landscape. There are alternative scenarios of the move to renewable energy where decentralization is delayed or circumvented, but these have their downside. They involve consumption of the mountains of dirty coal, as a society builds massive LQR infrastructure where forests of windmills sit on sculptured coastlines (Allen et al. 2001). Avoiding renewable energy appears to invite the four Horsemen of the Apocalypse, so we cannot afford to fail. And fail we will unless we can encourage the populace at large that the transition is worth it. The human focus and the emphasis on advice from lay opinion at this workshop are most encouraging at a time when deep concern for public opinion is not misplaced. The coming LQR society is set to devastate coastlines, deserts, forests, and wildlife. It is for this reason that the visionary tone of this workshop is so important. Even under the happiest outcome, ecological stress will be great. Precisely because of impending ecological disaster in the move to extensive use of renewable energy, only the best stewardship will do. The problem is large, so the view of the stewards of natural resources such as forests, wildlife, and fisheries must be at least as visionary as the most expansive view from the ridge.

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The Future of Landscape-Level Research at the Pacific Northwest Research Station

Thomas J. Mills[1]

Key Drivers of Landscape-Level Research

Station scientists at the Pacific Northwest Research Station (PNW) work to advance the basic understanding of how systems function, especially terrestrial, aquatic, and socioeconomic systems. This provides the foundation of scientific understanding to better understand the consequences and risks of choices made in managing the land. It also provides the foundation on which to help design new land management options.

In the 1990s, in response to key issues, Station scientists increasingly focused their research on the landscape scale. This workshop reflects a body of work designed by PNW to consciously examine this scale. In many ways, we have only started to understand systems at the landscape scale in the Pacific Northwest, but it is an important part of our research program that is already demonstrating that it holds considerable promise. We appreciate being able to share information with those of you who make land management decisions or affect those decisions and the scientists here who have validated and built on our research results.

Much of our landscape-scale research has focused on national forest land issues because they offer landscape-scale laboratories. Our researchers often work side by side with land managers as we conduct studies and assessments on the very large scales of the national forests. We also conduct landscape-scale research on other lands such as the state lands of Washington. Much of what we are learning is applicable to all ownerships. As we study forests at the landscape scale, I believe we can find some additional options that may create compatibility among interests and across ownerships.

What put us on the landscape trek? In part, it was the result of our fine-scale and single-discipline research. Although often initiated from a single disciplinary perspective, this research has produced important scientific findings. At the same time, it has shown that some of those fine-scale phenomena also were components of large systems. We have found that some relations exist and manifest themselves only at a large scale.

As we examined outbreaks of insects and disease during the past several decades, for example, we began to understand the need to look beyond the stand. Also our research on fire disturbance processes and smoke management led to a broader perspective. The ecological effects of forest fragmentation and the interactions between fragmentation and habitat quality for some wildlife species begged a landscape-scale view. Increasingly we understand that pattern and patches across the landscape affect relations such as those among the nesting, feeding, and migrating of some wildlife species.

In addition to our fine-scale research, some defining land management issues helped us to look at broader scaled relations. Issues such as management of old-growth forests, recovery of threatened and endangered species, and forest health are examples. These types of issues have been drivers of our research program, just as our scientific understanding has helped shape the character of these issues.

Land management issues such as these, reinforced by our past research, have led to the following overarching land management questions that demand broader scale, functionally integrated research: How do the effects of land management actions accumulate over space and time? What are the effects of interactions among different land units, and how do those interactions affect overall outcomes? Another related question, given the inability to treat all parcels, is, How can we prioritize among the numerous parcels to maximize our objectives?

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These questions require a landscape-scale perspective and integration among different scientific disciplines. Moving to broader scale is usually coupled with the need to study the interactions among different components of the land, as well as the interaction among the different land components within the landscape. Integration among physical and biological disciplines is needed, but integration between the biophysical and social sciences also is essential if we are to understand the full array of consequences of land management actions and to create new land management options.

The Station has a deep history of long-term research studies and an emerging body of landscape-scale research, but research integrated across disciplines at the landscape scale is only now emerging. Although working across disciplines can be complicated and time consuming, it is in the resulting comprehensive picture that policymakers likely will find solutions to complex problems.

Land Management Opportunities Among the Challenges

Not only does the landscape-scale perspective add significant complexity beyond what is apparent through a finer scale look at the land, it also holds the promise of land management opportunities not apparent at the finer scale. For example, if the focus is solely on the fine scale, a manager or the public might conclude that only the area being studied can provide some desired value. They might also conclude that all such sites must provide the same set of values. Our research has shown, however, considerable variability across the landscape. The land is not now uniform nor was it ever, even when nature was managing it. For example, not all sites on the west side of Oregon and Washington were prime salmonid habitat at any one time even in the past. And some of the most constraining laws, such as the Endangered Species Act, require only that values be provided on enough sites to meet an overall goal, not that those values need to be provided from every site. A landscape view helps us understand how a mosaic of uses might be scattered across the landscape. Each parcel might be devoted to delivery of some set of values with the designated uses moving across the landscape over time, as nature moved them.

Policymakers have tried to solve this challenge by implementing land allocations akin to land use zoning. Land allocations in national forest plans are a simple version of this. Our research challenge is to sufficiently understand the broad-scale phenomena so that creative solutions may be developed to provide an array of values that blend uses across the landscape, and even shift uses across time in a way that increases benefits and reduces negative effects and risks.

Building on the Foundation of Past Research

Many PNW scientists and their colleagues have presented examples of landscape-scale research at this workshop. The PNW Station is making a concerted effort to address the landscape scale. Broad-scale studies like that of land cover dynamics and land use changes described by Ralph Alig and the study of the implications of scale for the study of terrestrial wildlife populations by Martin Raphael are only two examples of the work presented here. The poster session showed a variety of projects related to landscapes that PNW has underway. And yet during this workshop, although we presented much, it was not all work conducted at the landscape scale by the Station. Some landscape research spans decades for issues such as insects and disease. Some of our research has just begun, and information is yet to be developed.

As with the rest of our research, much of this work on the landscape scale is conducted with colleagues at universities and through partnerships with land managers. John Cissel’s presentation of the Augusta Creek study was an example. Critical in our success is the ability to work with the National Forest System and other land managers on large tracts of land. The contribution we have made so far, our continued cooperation with universities, and our partnerships with land managers create a strong foundation from which to continue studies at a broad scale.

Challenges to Landscape-Level Research

In accomplishing landscape-level research, especially with research integrated across many disciplines, we face significant challenges. To make meaningful progress, we need to face and overcome these challenges.

We need to fully develop concepts, models, and especially testable hypotheses. For the most part, these do not yet exist. Questions abound, but rigorous scientific methods to answer the questions need to be developed further. Without the benefit of stronger methods, there is always the risk that the personal values of scientists will become embedded in the framing of questions or the interpretation of results.

Landscape-scale research often but not always, requires integration of several scientific disciplines. Success depends on our ability to understand interactions among biophysical components and between biophysical and social systems. But the science perspective of the different disciplines often focuses at widely divergent scales, and typically with very different boundaries. For example, most social science is conducted at broad scales and creates behavioral models developed at the broader spatial scales but still useful at smaller scales. The biophysical sciences, on the other hand, are challenged to "scale up" with both data and models. For scientists to address landscape issues, synthetic and interdisciplinary science must overcome these technical and conceptual difficulties. To date, we have mostly accomplished integrated research by synthesis of knowledge already gained. Instead, we need to plan for integrated approaches as we develop hypotheses, concepts, models, and methods. We must gain the ability to determine early in our research how we want to address the pieces to understand the whole.

Through its ability to bring together staff scientists and those from universities, the Station has contributed to and will continue to work toward such integrated research. The Station has an advantage in being able to bring scientists together, and we need to exercise that advantage.

Landscape science requires at least some large-scale experiments. Large-scale experiments are challenges from several perspectives. One is the difficulty of convincing land managers and the public that the search for knowledge should require testing ideas, and we are testing them because we do not know what the outcome will be, even as we are guided by a hypothesis. Even if land managers are willing to accept and participate in these experiments, management with uncertain outcomes is not consistent with the emphasis to define objectives and hold managers accountable for performance results. We have overcome this challenge in some places, such as the large-scale studies in the Willamette National Forest, but we need to build on those few successes, including working across ownership boundaries.

Even when we are successful with large-scale, designed experiments, we invariably have few replications. It is difficult to commit extensive acreages, and it is hard to find enough comparable sites. We need to somehow develop means of testing hypotheses that are not so dependent on large sample sizes. We will never have the sample sizes typical of fine-scale studies, but that cannot stop us from drawing defensible inferences.

We need to expand our capability to draw inferences from other than designed experiments. Modeling has long been a tool to learn about relations. Models will play an even more important role in large-scale research, but we need to develop better means to measure the confidence we can place in their results. We need to develop new methods to reveal the confidence, or in turn, the uncertainty, of our scientific information that describes large-scale relations.

Landscape research requires vast amounts of data. Other opportunities for collection of important landscape data may emerge as monitoring data are generated, such as is proposed for the federal lands in the range of the northern spotted owl. We will have to develop more rigorous data accumulation and data management systems than customarily are needed for finer scale research. This technological challenge emerged with the study of landscape relations in the interior Columbia basin as in the work described by Paul Hessburg. Just as important as the technology, however, is the discipline to use it.

Successfully addressing landscape-scale issues requires complex decisionmaking, often involving multiple agencies and landowners. A willingness to research transboundary effects is necessary, and success in both science and implementation will require public-private cooperation. These transboundary challenges highlight the importance of socioeconomic landscape research. Biophysical research alone simply will not be successful in providing the scientific information to deal with larger scale issues.

Landscape science may be burdened with the a priori expectation that it will produce more than scientific information. Scientists, managers, and the public may develop exaggerated expectations about the nature of results of studies about landscapes, perhaps even more than about finer scaled research studies. Sound scientific information is an essential ingredient to sound decisions, but information alone does not make decisions. Any decision invariably requires the integration of multiple components that can only be accomplished by value-based weighing of tradeoffs among those components. That is the stuff of decisionmaking, not science. While insisting that the available science must be fully and faithfully considered in the decision process, those responsible for research results must be careful to avoid the misperception that science "makes" decisions.

Conclusion

We have a strong foundation of research on which to build future landscape-scale research, and the PNW Station and others in the science community have already begun to do landscape-scale research. There are compelling scientific and policy reasons for conducting landscape-scale research, especially research integrated across scientific disciplines. Working with our research collaborators and land management partners, we hope to build on this foundation and make meaningful advances—advances that may not only help us better estimate the consequences and risks of current management options but also help us all create new options that might embody more compatibility among the many values society seeks from the land.

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