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14

Putting multiple use and sustained yield into a landscape context

14.1 Introduction

When managing natural resources, foresters, wildlife biologists, and other practitioners need to consider a vast array of technical information, along with a multitude of values, opinions, and perspectives – many of which may be in conflict and therefore difficult to resolve. Ongoing discussions about ecosystem management, conserving biological diversity, adaptive management, and sustainable development reflect heightened concerns about sustaining natural resources and resolving conflicts among competing interests and demands (e.g., Walters, 1986; Rowe, 1992; Grumbine, 1997; Bunnell, 1998; Tollefson, 1998; Yaffee, 1999).

In response to these and related concerns, the Secretary-General of the United Nations established the World Commission on Environment and Development in 1983, headed by Gro Harlem Brundtland, then Prime Minister of Norway. In their landmark assessment – commonly known as the Brundtland Report – the Commission firmly connected environmental degradation with diminished economic opportunity, human health, and quality of life. In addition, they proposed long-term strategies for achieving sustainable development in a world characterized by great extremes in resource availability and utilization. They suggested multilateral approaches to transcend national sovereignties, political ideologies, and scientific disciplines so that common problems could be identified and common goals pursued.

There is increasing recognition that a more comprehensive and integrated approach is needed to resource planning and management (Boyce and Haney, 1997; Kohm and Franklin, 1997; Vogt *et al.*, 1997). In this chapter, I begin with the premise that principles and concepts from landscape ecology can contribute in a significant way to practicing integrated resource management. I explore this premise by considering the science of landscape ecology in relation

to the two important management paradigms – multiple use and sustained yield – that have guided forest management in North America for the past 100 years.

14.2 Historical background

Gifford Pinchot is credited with bringing forest management to North America (Pinchot, 1987). Compared to the exploitation and destruction that occurred in North American forests during the nineteenth century, the public viewed Pinchot's message of regulating forest harvest, practicing efficient utilization, protecting forests from fire and other destructive agents, and applying science-based management as enlightened and progressive forest conservation. The fundamental tenets of forest management that are widely practiced today – namely multiple use and sustained yield – have their origins in Pinchot's admonitions.

Multiple use and sustained yield were codified into public law with the passage of the Multiple-Use Sustained-Yield Act of 1960. As a management philosophy, multiple use and sustained yield have served the national forests, and therefore the public, well. However, much has changed since their enactment and so it is worthwhile revisiting these guiding tenets to see how well they continue to serve the national interest as well as the forestry profession in this new age of conservation. In doing so, it is not my purpose to conduct a policy analysis or to survey the myriad of laws relating to public land management. Rather it is to explore the possible intersection between a widely applied management philosophy, as represented by multiple use and sustained yield, and the emerging scientific discipline of landscape ecology.

The definitions of multiple use and sustained yield that will be used in this chapter are those established by the Multiple-Use Sustained-Yield Act of 1960. As stated in the legislation (*The Principal Laws Relating to Forest Service Activities*, Agricultural Handbook no. 453, p. 156):

> Multiple use means the management of all the various renewable surface resources of the national forests so that they are utilized in the combination that will best meet the needs of the American people; making the most judicious use of the land for some or all of these resources or related services over areas large enough to provide sufficient latitude for periodic adjustments in use to conform to changing needs and conditions; that some land will be used for less than all of the resources; and harmonious and coordinated management of the various resources, each with the other, without impairment of the productivity of the land, with consideration being

> given to the relative values of the various resources, and not necessarily the combination of uses that will give the greatest dollar return or the greatest unit output.

The assumption inherent in this definition of multiple use is that many benefits and outputs, including "outdoor recreation, range, timber, watershed, and wildlife and fish," can be derived from the forest without impairing the integrity of the ecosystem.

Although the ordering of these benefits and outputs was interpreted by some at the time this legislation was crafted as having political connotations, the language in the Act did not specify a primary purpose for national forests. All statutory language, however, is subject to interpretation and the 1960 Act is no exception. Interpretations vary depending on vested interests, values, and perspectives. The public attitudes regarding forests and their resource are not static, they change with time and place. Bengston (1994) argued that a broad, deep, and enduring change in public attitudes and values has occurred in recent years, resulting in greater interest in recreational, wildlife, scenic, spiritual, and ecological values, compared to when Gifford Pinchot brought progressive forest management to North America. Many people have come to associate multiple use with management that emphasizes timber production to the detriment of other benefits and outputs, while others view the designation of an area dominated by a single use, such as a wilderness, as a violation of the multiple-use mandate.

Because of these ambiguities, Behan (1990) considered multiple use to be more a political than a scientific concept. Shands (1988) suggested that "multiple use" has become a pejorative term. He called for moving beyond the limits and negative connotations of the concept and articulating a "fresh management philosophy" that emphasizes managing for distinctive values on public lands. Compared to private lands, for example, public lands are better suited for providing long-rotation managed forests, unmanaged old-growth forests, habitat for wildlife requiring large home ranges and late-successional forests, opportunities for dispersed recreational activities, low road densities, minimum forest fragmentation, undeveloped lakes, and free flowing streams. According to Shands (1988), management for distinctive values is consistent with the interpretation of multiple use. It does not mean that every use will be provided on each unit of public land, but a wide range of uses and values will be provided on some lands (not necessarily public lands) somewhere on the broader landscape.

In addition to the problems of interpretation, there are operational problems associated with the multiple-use concept. Clearly, all multiple uses are not compatible everywhere and so conflicts are inevitable. Shands (1988) referenced a debate nearly 60 years ago between two titans of forestry – Samuel Trask Dana and G. A. Pearson – regarding the proper application of multiple

use. Dana thought all uses should be given equal consideration on every parcel of land, while Pearson argued that multiple use is best applied over large areas with priority given to specific uses on local parcels. The differences between these two views reflect a difference in spatial scale – a concept that is familiar to landscape ecologists.

Likewise, sustained yield is defined by Congress in the 1960 Act as (*The Principal Laws Relating to Forest Service Activities*, Agriculture Handbook no. 453, p.157):

> Sustained yield of the several products and services means the achievement and maintenance in perpetuity of a high-level annual or regular periodic output of the various renewable resources of the national forests without impairment of the productivity of the land.

Sustained yield has its roots in the belief that resources such as fish, wildlife, and forests can be managed for human benefit in perpetuity through scientifically based management and regulated harvest. Although sustained yield has been successfully applied at small spatial scales and over relatively short periods of time, e.g., a forest stand over one rotation, finding successful applications of sustained yield at large scales and over long time periods, e.g., at a regional level over multiple rotations, is more problematic. As a result, management of natural resources is increasingly viewed as an adaptive process in which we learn from practice, we monitor the outcomes of our management, and we adjust as we go (Walters, 1986).

14.3 Understanding landscapes

Before exploring the intersection between landscape ecology and the management concepts of multiple use and sustained yield, an understanding is needed about what constitutes a landscape. Forman and Godron (1986) recognized patches, corridors, and the matrix as the three elements that constitute all landscapes. A patch is an ecosystem differing in appearance from its surroundings. Normally, landscape ecologists define patches by their biotic composition simply because these elements are relatively easy to recognize, but patches can also be delineated from differences in their physical characteristics (Saunders *et al.*, 1998). Patches vary widely in their size, shape, distribution, density, and boundary condition, with much of this variation related to the scale at which landscape patches are viewed. Regardless of the basis for defining patches, no single spatial scale is dominant in defining patches and the patterns that they create.

Corridors are narrow strips of land that differ from the matrix on both sides (Forman and Godron, 1986). Corridors originate in the same way as patches and they often connect patches of similar composition in the landscape. In

human-dominated landscapes, roads and their rights-of-way are obvious examples of landscape corridors. As with all corridors, roads can facilitate the movement of organisms, especially humans, or they can act as filters or barriers to movement. Both patches and corridors are embedded in the landscape matrix, or the dominant land cover that differs in composition from individual patches or corridors.

Although landscapes have been described as a kilometers-wide mosaic over which local ecosystems recur (Forman and Godron, 1986), there is not a consensus among ecologists about the spatial scale at which landscapes occur. There is general agreement, however, that landscapes are associations of interacting ecosystems. Further, if ecosystems are accepted as the fundamental unit comprising landscapes and if ecosystems are considered to be tangible geographic units (as opposed to a set of interactions), then we can begin to ascribe properties to landscape ecosystems.

Ecosystems are volumetric segments of the earth that are expressed through their biotic communities as well as the physical environments that support organisms (Rowe, 1961; Christensen *et al.*, 1996; Barnes *et al.*, 1998). Moreover, ecosystems may be very small, such as an ephemeral pond in a forest, or very large, the global ecosphere. Here, I consider a landscape to be a geographic unit that encompasses multiple and interacting ecosystems, and extending at spatial scales ranging from a few hectares to many square kilometers in size. It is within this range of areal extent that humans commonly perceive landscapes (Forman, 1995).

Landscapes can be described in terms of their structure and function, as well as the magnitude, direction, and rate of change. Landscape structure, as measured by the size, shape, arrangement, and composition of landscape patches, reflects variation in the physical environment as well as natural disturbances and human activities. The interaction of these factors creates pattern in the landscape (Crow *et al.*, 1999). The distribution of patch sizes, a measure of landscape structure, generally follows a negative exponential relationship with many small patches and a few large patches. When considered on an area basis, however, the few large patches can represent a large share of the total landscape area. Large patches constitute important structural elements that provide critical habitat and isolation for large-home-range vertebrates, sustain viable populations of interior species, and provide linkages across landscapes that support processes that may be similar to those provided by corridors (Forman, 1995). Within a given landscape, the composition, size, and arrangement of patches affect flows of materials and energy, the movement of organisms, and more generally, the type, quality, and quantity of outputs and benefits derived. Yet this connection between the structure of a landscape (including its composition) and the derived outputs and benefits is rarely explicitly recognized.

Human activities tend to simplify the structure of a landscape as measured by complexity of patch shape and the range of patch sizes (Mladenoff *et al.*, 1993; Reed *et al.*, 1996). Human effects on landscape pattern are neither exclusive nor independent, but are typically interactive and cumulative (Crow *et al.*, 1999). Monitoring and analysis of these interactions and their cumulative effects are needed at the scale of a few hectares to many square kilometers (Reed *et al.*, 1996).

Function is the interaction among landscape ecosystems as measured by processes such as the flow of energy, movement and persistence of organisms, and fluxes of materials. Change refers to alteration in the structure and function of the landscape with time. There can be no ecological phenomena without change (Allen and Hoekstra, 1992). Land cover is transformed by several spatial processes overlapping in order, including perforation, fragmentation, and attrition (Forman, 1995). As the term suggests, perforation is the process of creating holes in the land cover that differ in composition from the general matrix. Fragmentation occurs when a contiguous patch is divided into smaller patches. Whenever a patch decreases in size, this form of land transformation is called shrinkage. And finally, when a patch disappears from the landscape, this is considered to be attrition (Forman, 1995).

An important aspect of landscape ecology, then, is the study of the reciprocal effects of spatial patterns on ecological processes (Turner, 1989; Pickett and Cadenasso, 1995). That is, landscape ecologists study both the cause and the effect of spatial heterogeneity. Emphasis on large-scale phenomena tends to reinforce the notion that humans are an integral part of almost all landscapes. Instead of attempting to study ecological phenomena devoid of human influences, landscape ecologists embrace the human influence when studying pattern and process.

14.4 Guidelines for multiple use and sustained yield from a landscape perspective

The following principles and concepts from landscape ecology contribute in a substantive way to practicing multiple use and sustained yield forestry.

14.4.1 Considering scale

Forest managers deal with complex issues that require considering the forest at many different spatial scales. A landscape perspective supports a multi-scale perspective for multiple use and sustained yield management. Because landscapes are spatially heterogeneous, their structure, function, and change are scale-dependent. That is, the measurement of spatial pattern and heterogeneity is dependent upon the scale at which observations and measure-

ments are made. The scale at which humans perceive boundaries and patches in the landscape may have little relevance to numerous flows or fluxes. Processes and parameters important at one scale may not be as important or predictive at another scale (Turner, 1989).

Forest managers often focus on individual stands. At this spatial scale, the manager's perspective is that of being within the forest, with the forest canopy extending above the observer. An equally valid perspective for management is that of observing the forest (and other landscape elements) from above the canopy (Crow and Gustafson, 1997a, b). The extent of the view and the amount of detail (i.e., the landscape grain) depend on the scale of observation and the technologies employed. There is no "correct scale" to view a forest; however, the landscape perspective or "view from above" greatly enhances the manager's ability to implement the concept of multiple use.

14.4.2 Managing in time and space

Since multiple use can not be practiced on every unit of land to the same degree or intensity, managers need to capitalize on the different capabilities and opportunities that various ecosystems provide. Yet a formal spatial framework is rarely presented when applying multiple-use management. When confronted with conflicting uses, resource managers tend to partition land into separate allocations to meet specific management goals. This approach works well when land is abundant and demands for its use are few, but the land base is finite and the demands for forest goods and services are many. Separate allocations result in administrative fragmentation and ultimately landscape fragmentation. This results in conflict and seemly intractable problems related to land use. The spatial framework provided by a landscape perspective facilitates a more integrated, holistic approach to resource management and conservation.

Resource managers are uncomfortable acknowledging that uncertainty is associated with the results of their actions, but in reality, there is a great deal of uncertainty due to lack of knowledge about the systems being managed and due to unanticipated events that alter outcomes. Instead of predicting a single outcome, Walters (1986) suggests defining a set of possible outcomes that are consistent with existing knowledge and historical experience, and then assigning odds or probabilities to the outcomes. Such an approach might be appropriate for estimating growth and yield of forests under management.

Researchers are not adept at predicting growth and yield over broad areas and long time periods. Most models of timber growth are based on measurements taken at small spatial scales, and in many cases, over short periods of time (Fries *et al.*, 1978; Ek *et al.*, 1988). When these predictors are applied over

broad areas and long periods of time, large cumulative errors are possible. Rarely are stochastic events such as extended droughts or losses due to outbreaks of insects or pathogens incorporated into growth models. These events may be rare in the short term, but they are common over the long term.

Regardless of the uncertainties associated with estimating growth and yield, projections at the scale of a national forest are the basis for important policy decisions such as establishing annual targets for timber harvesting. Both the spatial and temporal dimensions of scale need to be incorporated into the prediction of forest growth and yield.

14.4.3 Considering context

Because landscape ecosystems do not exist in isolation, it is important to consider forest stands or management areas within their broader spatial context. Most ecosystems have permeable boundaries that allow movement of species, materials, and energy across their boundaries. Proximity affects the degree of interaction among landscape ecosystems within the matrix. The degree of interaction, as measured by movement of species, material, and energy, drops sharply with distance. The rate of decrease is somewhat less for large patches compared to small patches.

Many studies have demonstrated the importance of landscape context on ecological processes. For example, Liu and Ashton (1999) used the spatially explicit model FORMOSAIC to study the interaction between landscape context and timber harvesting on tree diversity in a tropical forest. Forests adjacent to timber harvests provide important sources of seed for regeneration and so Liu and Ashton (1999) recommended maintaining species-rich forests in close proximity to harvested areas.

Clearly the application of the multiple-use concept benefits from evaluating the spatial and temporal context in which treatments occur so that potential conflicts are minimized and so that unintended and undesirable cumulative impacts of multiple actions can be better anticipated. Regional assessments, such as those conducted in the Pacific Northwest (FEMAT, 1993), the southern Appalachian region (SAMAB, 2001), or the Lake States (Minnesota, University of, 2001) and elsewhere, provide the means for considering local decisions and subsequent actions in a much larger social, economic, and ecologic context.

14.4.4 Hierarchical organizations

Theories and concepts relating to the hierarchical organization of ecological systems have developed in a much broader arena than landscape ecology, but landscape ecologists have contributed to the thinking about levels

Table 14.1. *National hierarchy of ecological units adopted by the US Department of Agriculture Forest Service*

Planning and analysis scale	Ecological units	Purpose, objective and general use
Ecoregion		
Global	Domain	Broad applicability for modeling and sampling. Strategic planning and regional assessments. International and national planning.
Continental	Division	
Region	Province	
Subregion	Section Subsection	Strategic planning, analysis, and assessment at the statewide, multi-agency level.
Landscape	Landtype Association	Forest or area-wide planning, watershed analysis.
Land Unit	Landtype Landtype Phase	Project level management and planning.

of organization and the relationships among these levels. Comprehensive discussions about hierarchical organization are found in O'Neill *et al.* (1986) and Allen and Hoekstra (1992) as well as others. The hierarchical organization of ecological systems, with smaller systems nested within larger systems, unites the concepts of context and scale. A hierarchical perspective helps managers evaluate broader-scale influences on finer-scale conditions and processes.

The description and inventory of forest ecosystems at multiple scales is the primary objective of the Ecological Classification and Inventory Systems (EC&I) adopted by the US Department of Agriculture Forest Service (Table 14.1). This is an example of using a hierarchical approach and ecological principles for classifying landscape ecosystems based on the physical environment (climate, physiography, soil,) and vegetation across scales ranging from global to local. The selection of an appropriate scale depends on the question or issue being addressed. The Ecoregion and Subregion levels of the national hierarchy provide useful contextual information for planning and managing at a national forest or even at a forest stand level. Crow *et al.* (1999) used Sections and Subsections (Table 14.1) to consider the interaction of the physical environment and land uses by humans in creating landscape patterns in northern Wisconsin. Host *et al.* (1988) compared variation in overstory biomass in forests on different Landtype Associations (Table 14.1) in northwestern Lower Michigan. The lowest levels of the national hierarchy – Landtype Association,

Landtype, Landtype Phase (Table 14.1) – provide operational units for management on the ground. Use of the hierarchy of ecological units improves the uniformity of resource information and facilitates the sharing of resource data across administrative and jurisdictional boundaries.

14.4.5 Landscape analysis and design

Given current demands for natural resources, spatially explicit planning and management are needed at the landscape level to produce "harmonious and coordinated management of the various resources." The process of designing landscapes begins with clearly articulating the management goals, along with analyzing existing and desired landscape patterns and processes (Diaz and Bell, 1997). This information is essential for preparing a landscape design. The ultimate design, obviously, should reflect the management goals stated at the beginning of the process. Computer visualization can also help in the design phase. The aesthetic value of landscapes, for example, can be evaluated using virtual images drawn by a computer (Pukkala and Kellomäki, 1988; Caelli *et al.*, 1997).

Harvesting timber profoundly affects landscape patterns. The practices of building roads and dispersing cutting units throughout a forested landscape, for example, are major contributors to forest fragmentation. With the help of spatial models, alternative cutting techniques have been derived that greatly decrease the amount of forest fragmentation through clustering harvest units or by harvesting timber in a progressive fashion across the landscape (Franklin and Forman, 1987; Li *et al.*, 1993; Wallin *et al.*, 1994; Gustafson and Crow, 1996).

14.5 Case studies

The following case studies illustrate the previously discussed general guidelines for thinking about multiple use and sustained yield from a landscape perspective. Since resource managers are usually responsible for only a portion of a landscape, the first case study was selected because it stresses collaborative approaches across ownerships for managing landscapes. The next two case studies illustrate concepts of landscape design within a single ownership – in this case, public lands.

14.5.1 The Pinelands National Reserve

The New Jersey pine barrens are a definable physiographic feature characterized by acidic, droughty, sandy soils, and by fire-dependent ecosystems dominated by pitch pine, (*Pinus rigida*), oaks (*Quercus* sp.), and ericaceous shrubs

such as *Vaccinium* and *Gaylussacia* (Forman, 1979; Good and Good, 1984). Although sparsely populated compared to most of the northeastern United States, the Pinelands are coming under increased developmental pressures from urban centers such as Philadelphia and Atlantic City. In 1976, federal legislation created the nation's first National Reserve when it became apparent that the Pinelands would not continue to exist as a functional ecological unit indefinitely without a regional plan to balance needs for increased development with conserving significant and representative Pinelands ecosystems. At least three of our four guiding tenets for landscape-level management – considering context, landscape analysis and design, and managing in time and space – have been incorporated into planning and managing the Pinelands.

State legislation implementing the federal Act provided a mechanism to guide, mitigate, and to some extent, regulate the effects of an increasing population on this regional ecosystem (Good and Good, 1984). The State of New Jersey was responsible for creating a comprehensive management plan for the Pinelands that, in turn, provided a coordinating framework for county and municipal governments when developing their local land management plans. To guide land-use planning for the Pinelands, maps depicting land capability based on flora, fauna, geology, soils, and hydrology were developed. Each land capability type has a distinct set of rules governing the types of land use allowed (Table 14.2). The combination of local plans developed within the context of a comprehensive regional plan provided a level of coordination and cooperation among various county and municipal jurisdictions that would be impossible if each political entity were acting independently. Considering biological and social factors locally as well as regionally provided managers, planners, and political leaders with valuable contextual information for making decisions.

The creation of land capability maps added a spatial element to planning land use in the Pinelands National Reserve and projecting desired future conditions added the temporal element. Opportunities for more intensive development were focused in areas categorized as Pinelands Towns, Villages, Rural Development Areas, and Regional Growth Areas (Table 14.2). The strategy was to direct new development to areas already developed, thus concentrating the effects to relatively few areas as opposed to dispersing the effects throughout the landscape. Concentrating development also increased the likelihood of keeping existing agricultural and forested lands in production as well as creating a system of reserves in which fire could be reintroduced in a limited way to the landscape. Although forest management was not intensive by modern standards, it was likely to become non-existent due to developmental pressures without comprehensive land-use planning. The maps of land capability combined with the guidelines for each category provided the basis for designing a landscape.

Table 14.2. *Land capability types identified in the comprehensive management plan and their associated land-use guidelines for the Pinelands National Reserve*

Land Capability Types	Guidelines
Preservation Area Districts	The most restricted allowable land-use category. Emphasizes the preservation of an extensive contiguous land area in its natural state while promoting compatible agricultural and recreational uses.
Forest Areas	Forested lands with less protection than Preservation Area. New development is limited to an average of one dwelling unit per 6.3 ha of privately owned, undeveloped upland.
Agricultural Production Areas	Areas where existing agricultural activities are important or where soils favor such activities. Prohibiting residential developments encourages continuance of agricultural activities.
Rural Development Areas Regional Growth Areas Pinelands Towns, Villages	More intensive and extensive development is focused in these land capability types. These areas are centered on locations that have already been extensively disrupted by development but includes some undeveloped lands in close proximity to present development.
Military and Federal Installation Areas	Federal lands. Often part of a Preservation Area District.

Source: Good and Good (1984).

Efforts to develop a comprehensive land-use plan for the New Jersey pine barrens expands upon the concept of multiple use and sustained yield as defined in federal legislation. In the case of the pine barrens, multiple use applies to the full spectrum of land uses, from urban development to high levels of protection and restoration of pineland ecosystems. Attempts to distribute varying intensities of management in time and space in the pinelands provide a useful model for public (and private) lands where increasing demands for goods and services from a finite land base are forcing planners to apply a more explicit spatial framework to land management. In the context of the Multiple-Use Sustained-Yield Act of 1960, sustained yield refers to the continuous flow of products. These outputs, however, are dependent on maintaining ecological processes that, in turn, sustain the productivity of the land. The focus, therefore, shifts from the output of goods and services demanded by people (e.g., timber, recreation, wildlife) to the inputs and processes (e.g.,

the soil, ecological services, biological diversity) necessary to maintain the outputs.

14.5.2 Forest planning on the Hoosier National Forest

Spatial models that combine geographic information systems (GIS) with remote sensing offer powerful tools for managing landscapes in time and space (Mladenoff and Baker, 1999). The use of one such a model, HARVEST, to evaluate several alternative management scenarios on the Hoosier National Forest in southern Indiana illustrates the utility of spatial models for analyzing and designing landscapes. The starting-points for HARVEST are a digital land-cover map derived from classifying remote sensing imagery and a digital stand map where grid-cell values reflect the age of each timber stand. The model allows control of the size and distribution of harvest units, the total area to be harvested per unit of time, and the rotation length as given by the minimum age that harvesting is allowed. HARVEST produces landscape patterns through time that have spatial attributes resulting from the initial landscape conditions and the planned management strategies by incorporating decisions typically made by resource managers (Gustafson and Crow, 1999).

The original forest plan for the Hoosier National Forest called for even-aged management using clear-cutting units averaging 15–18 ha in size and dispersed throughout the forest. Due to public opposition to this management approach, an amended plan was developed that proposed group-selection cuts that were less than 2 ha in size. In addition, reserve areas with no harvesting were identified, resulting in the concentration of timber harvesting on a smaller portion of the forest. Using these two very different management approaches as initial conditions for HARVEST, we projected changes in landscape structure on the Hoosier for eight decades. The group-selection approach resulted in a 60% reduction in harvest levels compared to the original forest plan. Despite this reduction in harvesting levels, group-selection did not result in increased forest interior (defined as >200 m from an edge) or decreased amounts of forest edge produced by timber management activities. It is not surprising that small, widely distributed harvest units result in fragmentation of the forest. In addition to the ecological argument, small and widely dispersed harvest units increase the cost of harvesting. Small harvest openings, however, are more acceptable to the public than large units and it is this visual aspect that is the determining factor for managers on the Hoosier National Forest.

Gustafson (1996) used HARVEST to simulate the clustering of harvest units in both time and space. In the simulation, the forest was partitioned into large management blocks in which harvesting was conducted in a single block for 50

years, then moved to another block for a similar time, until all blocks were eventually subjected to harvesting. The results from this simulation suggest that a strategy of blocking in time and space greatly reduced the amount of forest edge, greatly increased interior forest conditions, while maintaining an active program of timber harvesting.

In addition to evaluating changes in landscape patterns produced by alternative management scenarios, it is also possible to project changes in stand–age class distributions using models such as HARVEST, thus testing for sustainable yield on real landscapes. In simulating the effects of alternative management strategies on forest age structure on the Hoosier National Forest, Gustafson and Crow (1996) found gaps in the projected age structure of the forest that suggest a non-continuous flow of timber under more intensive harvesting given the current age structure of the forest.

14.5.3 Landscape Analysis and Design (LAD) on the Wisconsin National Forests

Using design principles presented in Diaz and Bell (1997), planners and managers on the Chequamegon and Nicolet National Forests established a network of representative ecosystems that serve as reference areas for the actively managed landscape matrix (Parker, 1997). The National Hierarchy of Ecological Units (Table 14.1) along with an inventory of ecologically significant features and an assessment of opportunities for protection, restoration, as well as traditional management provided the framework for designing the network and assuring adequate representation of the major ecosystems found on the forests.

The Landscape Analysis and Design (LAD) process had three main objectives (L. Parker, personnal communication). One was to create a representative array of high-quality reference areas to compare with landscapes under active management. A second objective was to identify areas where restoration of ecological processes is needed. The third and most important objective was to maintain biological diversity in a managed landscape. Total protection was not always the primary prescription for areas within the network. Most often, some level of manipulation such as the reintroduction of fire to the landscape and the application of innovative silvicultural techniques are necessary to restore important ecological characteristics and functions.

A logical complement to the LAD process would be to design a network of sites where intensive management for timber production is best suited on the Wisconsin National Forests. To establish a network of timber production areas, maps of ecological units based on the National Hierarchy (Table 14.1) combined with maps of existing roads could be utilized to identify highly productive eco-

systems with good access. When forest productivity areas are added to the LAD network, the rudiments of a landscape design encompassing the spectrum of multiple uses – from intensive utilization to protection – begin to emerge.

14.6 Summary

Most resource management activities produce changes in landscape pattern. The effects of these changes on biological diversity, aesthetic qualities, wildlife habitat, water quality, and even the production of forest commodities are poorly understood. Furthermore, land managers and planners often ignore interactions among different elements in a landscape, but instead treat the elements as a collection of independent pieces. Concepts and principles from landscape ecology – including managing in time and space, considering scale and context, and thinking about hierarchical organization – provide a guiding framework for managing natural resources in a much more holistic and integrative fashion.

The Multiple-Use Sustained-Yield Act of 1960 provides managers with a great deal of latitude when dealing with resource management issues. The basic concepts of multiple use and sustained yield do not need to be repudiated nor does the Act necessarily need to be changed. It is a matter of interpretation in light of modern-day realities that include a larger human population now that is placing much greater demands on natural resources on a limited land base. Given these demands, multiple use requires a formal spatial and temporal framework to guide its implementation and both inputs and outputs should be considered part of sustained yield. Concepts and tools from landscape ecology offer managers the means for designing landscapes in time and space for multiple uses, benefits, and values.

References

Allen, T. F. H. & Hoekstra, T. W. (1992). *Toward a Unified Ecology*. Columbia University Press, New York.

Barnes, B. V., Zak, D. R., Denton, S. R. & Spurr, S. H. (1998). *Forest Ecology*, 4th edn. John Wiley, New York.

Behan, J. (1990). Multiresource forest management: A paradigmatic challenge to professional forestry. *Journal of Forestry*, 88: 12–18.

Bengston, D. N. (1994). Changing forest values and ecosystem management. *Society and Natural Resources*, 7: 515–533.

Boyce, M. S. & Haney, A. (eds.) (1997). *Ecosystem Management: Applications for Sustainable Forest and Wildlife Resources*. Yale University Press, New Haven, CT.

Bunnell, F. L. (1998). *Policy and Practices for Biodiversity in Managed Forests*. University of British Columbia Press, Vancouver, Canada.

Caelli, T., Peng, L. & Bunke, H. (eds.) (1997). *Spatial Computing: Issues in Vision, Multimedia and Visualization Technologies*. World Scientific, River Edge, NJ.

Christensen, N. L., Bartuska, A. M., Brown, J. H., Carpenter, S., D'Antonio, C., Francis, R., Franklin, J. F., MacMahon, J. A., Noss, R. F., Parsons, D. J., Peterson, C. H., Turner, M. G. &

Woodmansee, R. G. (1996). The report of the Ecological Society of America committee on the scientific basis for ecosystem management. *Ecological Applications*, 6: 665–691.

Crow, T. R. & Gustafson, E. J. (1997a). Concepts and methods of ecosystem management: Lessons from landscape ecology. In *Ecosystem Management: Applications for Sustainable Forest and Wildlife Management*, eds. M. Boyce & A. Haney, pp. 54–67. Yale University Press, New Haven, CT.

Crow, T. R. & Gustafson, E. J. (1997b). Ecosystem management: Managing natural resources in time and space. In *Creating a Forestry for the 21st Century*, eds. K. A. Kohm & J. F. Franklin, pp. 215–228. Island Press, Washington, D.C.

Crow, T. R., Host, G. E. & Mladenoff, D. J. (1999). Ownership and ecosystem as sources of spatial heterogeneity in a forested landscape, Wisconsin, USA. *Landscape Ecology*, 14: 449–463.

Diaz, N. M. & Bell, S. (1997). Landscape analysis and design. In *Creating A Forestry for the 21st Century*, eds. K. A. Kohm & J. F. Franklin, pp. 255–269. Island Press, Washington, D.C.

Ek, A. R., Shifley, S. R. & Burk, T. E. (1988). Forest growth modelling and prediction. *Proceedings of the IUFRO (International Union of Forestry Research Organizations) Conference*, SAF 87–12. Society of American Foresters, Washington, D.C.

FEMAT [Forest Ecosystem Management Team] (1993). *Forest ecosystem management: An Ecological, Economic, and Social Assessment*. Joint publication of the US Department of Agriculture Forest Service; Department of Commerce; National Oceanic and Atmospheric Administration and National Marine Fisheries Service; US Department of the Interior Bureau of Land Management, Fish and Wildlife Service, and National Park Service, and Environmental Protection Agency; Washington, D.C.

Forman, R. T. T. (ed.) (1979). *Pine Barrens: Ecosystem and Landscape*. Academic Press, New York.

Forman, R. T. T. (1995). *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge University Press, Cambridge, UK.

Forman, R. T. T. & Godron, M. (1986). *Landscape Ecology*. John Wiley, New York.

Franklin, J. F. & Forman, R. T. T. (1987). Creating landscape patterns by forest cutting: Ecological consequences and principles. *Landscape Ecology*, 1: 5–18.

Fries, J., Burkhart, H. E. & Max, T. A. (eds.) (1978). *Growth Models for Long-Term Forecasting of Timber Yields*. Publication no. FWS-1–78. School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Good, R. E. & Good, N. F. (1984). The Pinelands National Reserve: An ecosystem approach to management. *BioScience*, 34: 169–173.

Grumbine, R. E. (1997). Reflection on "what is ecosystem management?" *Conservation Biology*, 11: 41–47.

Gustafson, E. J. (1996). Expanding the scale of forest management: Allocating timber harvests in time and space. *Forest Ecology and Management*, 87: 27–39.

Gustafson, E. J. & Crow, T. R. (1996). Simulating the effects of alternative forest management strategies on landscape structure. *Journal of Environmental Management*, 46: 77–96.

Gustafson, E. J. & Crow, T. R. (1999). HARVEST: Linking timber harvesting strategies to landscape patterns. In *Spatial Modeling of Forest Landscape Change*, eds. D. J. Mladenoff & W. L. Baker, pp. 309–332. Cambridge University Press, New York.

Host, G. E., Pregitzer, K. S., Ramm, C. W., Lusch, D. P. & Cleland, D. T. (1988). Variation in overstory biomass among glacial landforms and ecological land units in northwestern Lower Michigan. *Canadian Journal of Forest Research*, 18: 659–668.

Kohm, K. A. & Franklin, J. F. (eds.) (1997). *Creating a Forestry for the 21st Century: The Science of Ecosystem Management*. Island Press, Washington, D.C.

Li, H., Franklin, J. F., Swanson, F. J. & Spies, T. A. (1993). Developing alternative forest cutting patterns: A simulation approach. *Landscape Ecology*, 8: 63–75.

Liu, J. & Ashton, P. S. (1999). Simulating effects of landsape context and timber harvest on tree species diversity. *Ecological Applications*, 9: 186–201.

Minnesota, University of (2001). http://www.ncfes.umn.edu/gla

Mladenoff, D. J. & Baker, W. L. (eds.) (1999). *Spatial Modeling of Forest Landscape Change:*

Approaches and Applications. Cambridge University Press, New York.

Mladenoff, D. J., White, M. A., Pastor, J. & Crow, T. R. (1993). Comparing spatial pattern in unaltered old-growth and disturbed forest landscapes. *Ecological Applications*, 31: 294–306.

O'Neill, R. V., DeAngelis, D. L., Waide, J. B. & Allen, T. F. H. (1986). A hierarchical concept of ecosystems. *Monographs in Population Biology*, 23: 1–272.

Parker, L. (1997). Restaging an evolutionary drama: Thinking big on the Chequamegon and Nicolet National Forests. In *Creating a Forestry for the 21st Century*, eds. K. A. Kohm & J. F. Franklin, pp. 218–219. Island Press, Washington, D. C.

Pickett, S. T. A. & Cadenasso, M. L. (1995). Landscape ecology: Spatial heterogeneity in ecological systems. *Science*, 269: 331–334.

Pinchot, G. P. (1987). *Breaking New Ground*. Island Press, Washington, D. C. (Reprinted; originally published by Harcourt, Brace, and Co., New York, 1947.)

Pukkala, T. & Kellomäki, S. (1988). Simulation as a tool in designing forest landscape. *Landscape and Urban Planning*, 16: 253–260.

Reed, R. A., Johnson-Barnard, J. & Baker, W. L. (1996). Fragmentation of a forested Rocky Mountain landscape, 1950–1993. *Biological Conservation*, 75: 267–277.

Rowe, J. S. (1961). The level-of-integration concept and ecology. *Ecology*, 42: 420–427.

Rowe, J. S. (1992). The ecosystem approach to forestland management. *Forest Chronicle*, 68: 222–224.

SAMAB [South Appalachian Man and the Biosphere Program] (2001). http://samab.org

Saunders, S. C., Chen, J., Crow, T. R. & Brosofske, K. D. (1998). Hierarchical relationships between landscape structure and temperature in a managed forest landscape. *Landscape Ecology*, 13: 381–395.

Shands, W. E. (1988). Beyond multiple use: Managing national forests for distinctive values. *American Forests*, 94: 14–15, 56–57.

Tollefson, C. (1998). *The Wealth of Forests: Markets, Regulations, and Sustainable Forestry*. University of British Columbia Press, Vancouver, Canada.

Turner, M. G. (1989). Landscape ecology: The effect of pattern on process. *Annual Review of Ecology and Systematics*, 20: 171–197.

Vogt, K. A., Gordon, J. C., Wargo, J. P., Vogt, D. J., Asbjornsen, H., Palmiotto, P. A., Clark, H. J., O'Hara, J. L., Keaton, W. S., Patel-Weynand, T. & Witten, E. (1997). *Ecosystems: Balancing Science with Management*. Springer-Verlag, New York.

Wallin, D. O., Swanson, F. J. & Marks, B. (1994). Landscape pattern response to changes in pattern generation rules: Land-use legacies in forestry. *Ecological Applications*, 4: 569–580.

Walters, C. (1986). *Adaptive Management of Renewable Resources*. Macmillan, New York.

Yaffee, S. L. (1999). Three faces of ecosystem management. *Conservation Biology*, 13: 713–725.