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Volume II

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Ecological Stewardship

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- **Biological and Ecological Dimensions**
- **Humans as Agents of Ecological Change**

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A practical reference for scientists and resource managers

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Scale Considerations for Ecosystem Management

Jonathan B. Haufler, Thomas Crow, and David Wilcove

Key questions addressed in this chapter

- *Spatial and temporal components of scale that are important to ecosystem management.*
- *Why careful consideration of scale is critical to ecosystem management.*
- *Criteria and suggestions for determining the extent of planning landscapes.*
- *Considerations in identifying appropriate resolution of mapping or data.*
- *Time-spans for ecosystem management planning*
- *Time-spans for historical perspectives.*

Keywords: Landscape planning, spatial scale, temporal scale, mapping

1 INTRODUCTION

One of the difficult challenges facing ecosystem management is the determination of appropriate spatial and temporal scales to use. Scale in a spatial sense includes considerations of both the size area or extent of an ecosystem management activity, as well as the degree of resolution of mapped or measured data. In the temporal sense, scale concerns the duration of both natural and human induced disturbances, duration and time intervals of successional trajectories, the appropriate planning horizon of future activities, and the length of any historical perspective.

A review of literature relating to scale as a component of ecosystem or natural resource management reveals how recently identified this topic is, with considerable focus of attention only within the last two decades. Early plant ecologists such as Clements (1916) and Tansley (1924) addressed questions about plant dynamics at a stand (homogeneous group of plants) level. This focus dominated debates concerning species composition, stand structural relationships, and successional trajectories through the next 50 years. Similarly, most animal ecologists focused their attention on the relationships among species, or in describing stand-level habitat conditions required by different species. Leopold (1933) contributed a broader view of wildlife–habitat relationships by introducing the multi-stand concepts of edge, interspersion, and juxtaposition. The importance of integrating regional geography and vegetation science was first termed landscape ecology by Troll (1939), as discussed by Turner and Gardner (1991). Greig-Smith (1952) discussed the importance of scale in evaluating the distributional patterns of plants. However, it was not until the 1980s that scale issues relative to resource management became a major component in the ecological literature. Schneider (1994:2) stated "In reading the ecological literature prior to 1980, I gained the impression that nearly all papers before 1980 treat scale either implicitly, or not at all." He attributed this partially to the relatively recent technological advances in computers, geographical information systems (GIS), and remote sensing tools that have facilitated many new types of scale analyses.

Ecosystem management has emerged as a way of addressing increasingly complex management planning needs. It can be defined in various ways, but regardless of a specific definition, it generally requires management decisions over a large geographic area (Gregg 1994). Effective ecosystem management will need to utilize many of the tools developed by the expanding field of landscape ecology. As Wiens (1992) noted, scale issues are one of the largest future challenges to ecologists.

In this paper on scale considerations, we address the following key issues:

- Spatial and temporal components of scale that are important to ecosystem management.
- Why careful consideration of scale is critical to ecosystem management.
- Criteria and suggestions for determining the extent of planning landscapes.
- Considerations in identifying appropriate resolution of mapping or data.
- Time-spans for ecosystem management planning
- Times-spans for historical perspectives.

Scale considerations are integrally linked to the definition and objectives of ecosystem management. Ecosystem management generally involves the consideration of ecological, social, and economic objectives, each of which will require different scale considerations. Although all three of these are important objectives for successful ecosystem management, this paper will emphasize the consideration of scale issues primarily for ecological objectives.

2 BACKGROUND FOR SCALE CONSIDERATIONS

Scale is defined by the size and extent of the observations in time and space as well as by the resolution (i.e., pixel size or grain) of the measurements. Scale is relative because it is either large or small compared to some reference generally defined by an observer (Hoeskstra et al. 1991). The discussion of scale relative to ecosystem management requires the use of numerous terms, some of which often have different meanings. The use of scale terminology has differed somewhat between ecologists and geographers. Geographers use the terms large and small scale to describe the scale of a map, with a large-scale map depicting less land area per cm of map than a small-scale map. Ecologists have generally referred to large scale as a description for an analysis of a large-sized area. In this paper, we define terms in the following ways:

- *size or extent*: the amount of area or length of time contained in a delineated landscape or time-span, or a measure of its breadth and width or duration;
- *stand*: an identified area with relatively homogeneous structure and composition of vegetation;
- *resolution*: the level of detail, such as pixel size or graininess, that is incorporated into the mapping of an area or in the collection of data;

- *coarse filter*: an approach to ecosystem management that involves providing for an appropriate mix of ecological communities across a planning landscape;
- *fine filter*: an approach to ecosystem management that involves a focus on the needs of individual species or groupings of species as a basis for landscape planning;
- *coarse scale*: a level of resolution or grain size used in mapping or measuring data based on units such as large pixel sizes, large grain, broad categories, etc.;
- *fine scale*: a level of resolution or grain size used in mapping or measuring data based on units such as small pixel sizes, small grain, detailed data, etc.;
- *broad scale*: an area of analysis or management with a large extent, containing a relatively large amount of acreage or a long duration;
- *small scale*: an area of analysis or management with a small extent, containing a relatively small amount of acreage or a short duration.

How we perceive an object or a phenomenon is greatly influenced by the scale, both in space and time, at which it is viewed. This rather obvious fact has important implications for both science and resource management (Hoekstra et al. 1991). In many published studies, there is no recognition of the sensitivity of the results to the scales at which they are conducted. Indeed, it is not unusual for the same question to be studied at many different spatial and temporal scales. In ecosystem management, the approach used and objectives being addressed will have a direct bearing on the appropriate scale to use. If a fine filter approach is being used, then the planning environment should consider the needs of the specific species of interest. Typically resource managers have mapped landscapes into stands on the basis of what they observe to be homogeneous conditions relative to their land management objectives. However, from the vantage point of a small mammal, the important components of a stand might look completely different, and scale related issues would be very different. Instead of looking at the composition and structure of vegetation in a forest in terms of the overstory of trees, the critical scale might be the arrangement and patchiness of the understory herbaceous vegetation. Addressing a question at the wrong scale often leads to a failure of explanation and to the wrong conclusions (Wiens 1989, Turner 1990).

Turner and Gardner (1991) distinguished between scale and level of organization. They defined scale as "the spatial or temporal dimension" (1991: 6), whereas level of organization was defined as "the place within

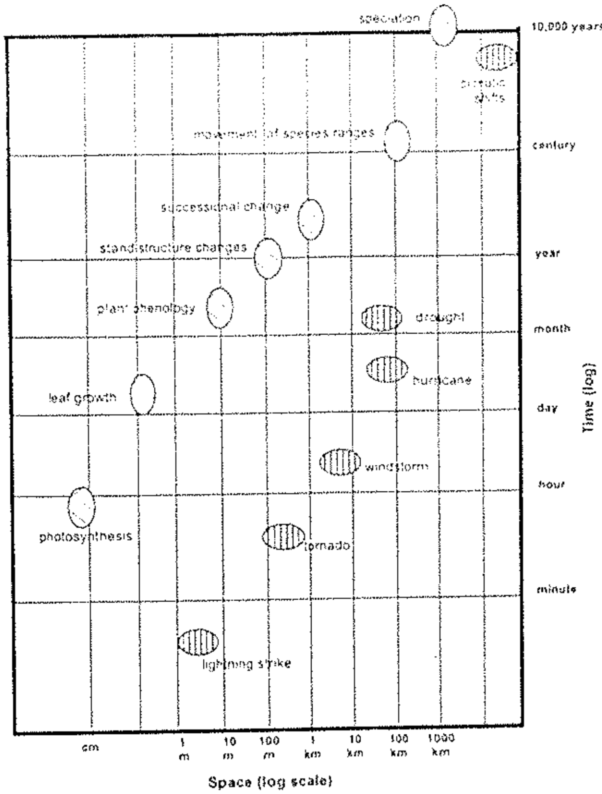

Fig. 1. Space/time hierarchy (after Holling 1995) for plant biotic processes and climatic disturbance events.

some biotic hierarchy" (1991: 6). Others have described scale as operating in a hierarchical fashion. Spatial hierarchies have been described for ecological diversity from niches to biospheres (Miller 1996), for ecological classification from sites to domains (Ecomap 1993), for disturbance activities from small mammal influences to major floods (Bourgeron and Jensen 1994), and for aquatic communities from channel units to river basins (Maxwell et al. 1995). Temporal hierarchies have been described for aquatic systems (Maxwell et al. 1995) and disturbance regimes (Bourgeron and Jensen 1994). Holling (1995) (Fig. 1) depicted a combined spatial and temporal hierarchy. Hierarchy theory provides an organizing framework to search for common properties across broad classes of complex systems, including physical, biological, social, and artificial systems. It is important to recognize these hierarchical levels of organization, and their potential influences on defining appropriate scales.

How do we take fundamental information about ecological processes obtained at fine scales (e.g., physiological response of leaves to elevated levels of ozone) and apply it to responses observed at broad scales (e.g., a landscape, a region, or even the entire ecosphere)? Understanding the properties of complex hierarchical organizations is useful in addressing this question (Pattee 1973, Simon 1973). For example, the transfer of information from one level of ecological organization to another is not a simple additive process. Vital information from lower levels in a hierarchy may be extraneous information at higher levels of organization. Furthermore, levels in an organizational hierarchy can be isolated from one another because they operate at distinctly different rates. A leaf, for example, is sensitive to changes in light conditions that can be measured in seconds and minutes. A forest stand integrates this information over weeks, months, and growing seasons, and its growth responses are measured in these timeframes. Successional change influences light conditions over years and decades. At each level in the organizational hierarchy, new organizing principles apply and new properties emerge, so properties of whole systems cannot effectively be predicted from the properties of simpler subsystems (Allen and Starr 1982).

What is an appropriate area (extent) for ecosystem management and planning? In determining extent, numerous factors should be considered, including ecological, economic, legal, political, and other social considerations, all of which are influenced by different factors operating at potentially different scales. This determination must consider the minimum-size area that is capable of addressing the stated objectives of the initiative as well as the maximum-size area that can feasibly be included from the standpoint of data collection, data storage and analysis, collaborative partnerships, and the resources available to do the job. The extent of the area can also influence the resolution to be used in mapping or data collection. The data must have the necessary or required precision to achieve the desired objectives, but also be feasible to collect, store, and analyze. No one scale of extent or resolution will meet all of the objectives of ecosystem management, but instead, multiple spatial scales are likely to be incorporated into the decision-making process. Project planning can involve considering a range of spatial scales from a few hectares to millions of hectares. In reality, however, decisions are most often made at local levels by people working on the ground. It is important that these decisions be made within the broader context provided by a landscape or regional assessment or a regional planning framework (Weintraub and Cholacky 1991, Crow and Gustafson 1996).

Time-frames to be used in ecosystem management also require careful considerations. The planning time-frame for ecosystem management must consider the practical realities of legal, political, and legislative constraints, but also the relevance and requirements of ecological parameters. Time-frames for historical perspectives must balance the availability of information, the influences of industrial societies on disturbance regimes, as well as factors such as global climate changes (e.g., ice ages), shifts in species' ranges and interactions, and evolutionary processes.

3 RELEVANCE OF SCALE TO ECOSYSTEM MANAGEMENT

Ecosystems are not closed, self-supporting systems, but rather are parts of larger interacting systems. Significant problems arise if ecosystems are treated as an isolated "entity." Rather, the ecosystems in an area must be viewed in the context created of the broader surrounding landscape. For example, providing habitat for forest interior birds often involves identifying within-stand areas of sufficient distance from an edge to provide protection from parasitism from brown-headed cowbirds (*Molothrus ater*) (Brittingham and Temple 1983, Reese and Ratti 1988). However, Robinson (1990) reported that the Shawnee National Forest was so saturated with cowbirds from the surrounding agricultural landscape that wood thrush (*Hylocichla mustelina*) nests were just as heavily parasitized (90% parasitism) at 400 m from an edge as at the edge. In contrast, Stribley (1993) found that in the primarily forested area of northern Michigan, cowbird parasitism was not a problem for nests at any proximity to edges, if agricultural lands or other cowbird foraging areas were located farther than 3 km from the site. Thus, surrounding lands can have a significant influence on relationships occurring within similar stand types in two different landscapes, and can significantly influence the character of a habitat patch (Janzen 1986).

Maintaining biological diversity, including genetic, species, and ecosystem levels, is one generally identified objective of ecosystem management. Attainment of ecological objectives, such as maintaining biological diversity, requires at least some minimum spatial area and time span. A fine filter approach is typically used for maintaining viable populations with sufficient genetic diversity and interchange to avoid inbreeding concerns and to provide sufficient resilience against demographic or environmental stochasticities. In contrast, a coarse filter approach, strives to provide the ecological communities necessary to maintain ecosystem function and integrity, and thus provide for viable populations of species within these ecological communities over an appropriate time span.

The area required to meet these ecological objectives can vary greatly, especially depending on how temporal considerations are factored into the planning effort. For example, maintenance of population viability is an essential component of ecological objectives relating to biodiversity. Population viability analysis attempts to predict the probability of persistence of a plant or animal population over a specified time period under various habitat conditions (see Noon et al. and Holthausen et al., this volume,). Viable populations of different species will have different area requirements that need to be factored into the planning effort. Roloff and Haufler (1997) described the different home range requirements of snowshoe hare (*Lepus americanus*) and Canadian lynx (*Felis lynx*) and how they relate to population viability. Population viability of snowshoe hare may be achieved in a much smaller area than Canadian lynx. Lynx depend upon the distribution and population sizes of snowshoe hare over a larger area. Thus, assuring adequate consideration for population viability of lynx requires that population distribution and relative size for snowshoe hare be determined first. Snowshoe hare habitat requirements must be addressed at scales appropriate to this species. Data on hare relative abundance are then aggregated into larger spatial scales that more closely approximate the areas required by lynx populations. Viability analyses for both of these species at appropriate scales can then be factored into analyses of ecosystem diversity that can occur for landscapes of an even larger extent.

Maintaining population viability of species must also address important temporal questions. Managers must select a time-span for assessing population viability, a decision that typically reflects a blend of ecological and political concerns as well as realistic long-term planning capabilities. In the Pacific Northwest, for example, federal land management agencies chose a 100-year time-span for predicting the impacts of different timber-harvest levels on wildlife associated with late-successional forests (Forest Ecosystem Management Assessment Team 1993). This time-span might seem long relative to actual applicability of forest plans, which seldom stay consistent for even 10 years. However, 100 years is a relatively short time-span when viewed from the context of the average "life span" of a species (i.e., the time a species survives before it goes extinct or evolves into new species). Based on fossil records, Ehrlich and Wilson (1991) reported that the life span of most species has ranged from one to ten million years. Species exist as aggregates of discrete populations. Individual populations of a species may exist for a much shorter period of time than the life span of the species, and it is only when the last population has expired that the species becomes extinct. By some estimates, because of human activities, the extinction rate of species today may be nearly 100 times the average level of the past 50 million years (Ehrlich 1986). When viewed from this temporal perspective, the importance of populations of a species as interim contributors to an evolving species continuum becomes more apparent.

Another temporal concern is the persistence or rates of successional change within natural communities. Some ecosystems, such as prairies or oak (*Quercus* spp.) savannas, were historically maintained by frequent (1–25 year interval) low intensity ground fires (Noss and Cooperrider 1994). Other systems, such as the Sitka spruce (*Picea sitchensis*) forests along the Washington coast may have fire-return intervals of up to 1,100 years (Fahnestock and Agee 1983), with wind events as a disturbance factor occurring on a more frequent and persistent basis (Ruth and Harris 1979, Agee 1993). Thousand-year disturbance regimes challenge the capabilities of our planning time-spans (see White et al., Engstrom et al., this volume)..

The level of detail or resolution of data used in making ecosystem management decisions can also vary depending on the approach being used. Using a fine filter approach or addressing the needs of one or more species may require fine scale data to describe adequately specific habitat requirements. Using a coarse filter approach to identify the diverse communities necessary to provide for ecosystem diversity may require a lower resolution, or coarser scale data, although finer scale data should work equally well assuming data handling capabilities are sufficient. Thus, scale considerations, both spatial and temporal, are significant concerns in planning efforts that address biodiversity objectives.

Ecosystem analyses must span several scales whenever the management actions being considered affect ecological processes that operate at different scales. For example, a timber harvesting activity has a direct effect on the process of regeneration at the stand level. But the same activity can, through cumulative effects, change sediment deposition and insect population dynamics at the watershed level and economic outcomes at a local community level. However, if one were to consider even all the ecological processes that could be potentially affected, the analysis would quickly get out of hand. Obviously, some practical bounds are essential. Some practical tools for ecosystem management are also needed. Decision-support models such as the northeast Decision (Kollasch and Twery 1995) and spatial models such as the allocation model HARVEST (Gustafson and Crow 1996), or the forest succession and landscape management model LANDIS (Mladenoff et al. 1996) are helpful for evaluating multiple factors and interactions at several spatial scales.

4 SCALE CONSIDERATIONS

Scale considerations that should be addressed in any ecosystem management process include:

- the extent of the planning landscape;

- the appropriate resolution for mapping or data collection;
- the planning time-span; and
- the time-span for an historical perspective.

4.1 Extent of Planning Landscape

One of the first steps in ecosystem management, following an initial identification of the participants and management objectives, is determining the extent and boundary(ies) of the planning landscape (Haufler et al. 1996). This involves considering the appropriate size of the landscape, and the boundary criteria. Haufler et al. (1996: 201) listed the following as criteria for delineating ecological boundaries:

- Similar biogeoclimatic conditions that influence site potentials.
- Similar historical disturbance regimes that influence vegetation structures and species compositions.
- Adequately sized landscape to provide sufficient ranges of habitat conditions to assure population maintenance of the majority of native species that historically occurred in the planning landscape, excluding certain species such as megafauna. Megafauna or species with low population densities will require analyses at broader scales where contributions from landscapes are aggregated to address population maintenance of these species.
- Recognition of maximum size to avoid practical operational limitations in terms of data management, implementation restrictions, and number of cooperating landowners necessary for successful plans.

Ecomap (1993) and Maxwell et al. (1995) provide a hierarchical classification for boundary determination that can be used to define a planning landscape. Haufler et al. (1996), using the above criteria and classification, advocated using the section or aggregates of subsections level (equivalent to Bailey's subregions (Bailey 1995, 1996)), to provide an appropriate landscape size to meet ecological objectives while being operationally functional. In Idaho, Haufler et al. (1996) described the Idaho Southern Batholith landscape comprised of an aggregation of subsections containing 2.3 million ha within the Idaho Batholith Section (McNab and Avers 1994). In Washington State, an aggregation of subsections was selected to delineate the 1.1 million ha Central East Cascade planning landscape (D. Volsen, Boise Cascade Corp., pers. comm.) In Minnesota, the entire Northern Minnesota/Ontario Peatlands Section was identified as a planning landscape for an ecosystem management initiative in that state (B. Kernohan, Boise Cascade Corp., pers. comm.). Within each of these planning landscapes, an ecosystem diversity matrix (Haufler 1994, 1995, Haufler et al. 1996) was then developed to characterize and quantify the forested ecosystems. This matrix provides for the quantification of ecological land units within the planning landscape. An additional criteria for delineating planning landscapes is that ecological land units within the landscape should be consistent enough throughout the landscape that they have an acceptable level of variability for key habitat variables or characteristics (Roloff 1994). In other words, all stands that comprise an ecological land unit should have similar enough composition, structure, or other characteristics so that habitat variables that describe the unit have small enough variance for determining habitat quality or quantity for a species.

Other ecosystem management initiatives, with different objectives or organizational structures, have used different scales. The Federal government delineated the Interior Columbia Basin Ecosystem Management Project as a planning landscape for an ecosystem management assessment, focusing on the Federal land holdings (Quigley et al. 1996). The assessment area included more than 58 million ha. At the other end of the scale gradient, the Watershed Analysis Coordination Team (1995) recommended conducting ecosystem analyses based on watersheds of 4500–52,000 ha in size.

No single scale exists for describing ecosystem patterns or diversity (Levin 1992, Noss 1990). The inherent complexity of landscapes results in a mozaic of both micro- and macro-site conditions that provide for the range of patterns apparent at different scales. Turner et al. (1994: 76) stated "View the landscape as a whole and use landscape-level indices to measure pattern at multiple scales. Do not focus solely on single, simple concepts like patches and corridors, and recognize that these concepts are scale-dependent." These views are not inconsistent with a hierarchically based delineation of landscapes for planning purposes. When a planning landscape is delineated, it should contain various descriptors of ecosystem complexity within the planning landscape, and allow interpretation of this complexity into larger-size areas in the hierarchical classification.

Most past management planning has utilized legal, political, and ownership boundaries as the basis for decisions. Although these boundaries remain critical, ecosystem management has added new ecological criteria to land management planning. These new criteria require the consideration and identification of ecological boundaries and scales. The social and economic objectives of an ecosystem management initiative must incorporate the ecological boundaries of the landscape planning unit, but will usually reflect economic markets, political structures, and social influences. All of these operate at multiple-spatial scales. For example, a local community will have many components of its quality of life influenced by the surrounding landscape. The surrounding landscape will largely determine the scenery, recreational opportunities, opportunities for firewood cutting or mushroom picking, as well as commercial extraction to support local commodity-based industries. This same landscape will have additional objectives placed on it by state authorities to meet objectives such as water quality standards. Additional national priorities for wilderness, mineral exploration, or other objectives may override local objectives. Desires at the local level for commodity-based industry are dependent on the economics of global markets. Conversely, there is the possibility that local restrictions on commodity extraction may raise costs of a local supply of commodities to high enough levels that supply is shifted to more distant sources. Whether or not this happens depends upon a complex set of economic factors, but it has the potential to "export" environmental problems to other places with less stringent environmental safeguards.

Meshing the social and economic with the biological and physical worlds remains a major challenge facing resource managers. Significant advances have been made in integrating these disciplines under the general rubric of ecological economics (Constanza et al. 1991). In this emerging science, great importance is attached to the interaction of environment and economics and to themes common to our chapter such as multi-scale synthesis, hierarchical theory, and interconnections.

4.2 Resolution Issues for Mapping or Data Collection

The resolution of the mapping units and data used in ecosystem management can have a significant influence on the conclusions of an ecosystem analysis. For example, Gap Analysis has used a fairly coarse scale (1 km pixel) in some of the state analyses. This means that each pixel can be assigned only a single vegetation or ecosystem characteristic. At this resolution, plant communities that typically occur in relatively small patches; for example willow (*Salix* spp.) along riparian zones, will never occur on a map of vegetation types. Species dependent on such plant communities, such as the yellow warbler (*Dendroica petechia*) in much of the Western U.S. will not be recognized as having any available habitat, even though relatively significant amounts of habitat may exist. Thus, using a very coarse scale of analysis, yellow warblers might be identified as a species of concern because of a lack of sufficient resolution to identify the presence of suitable habitat.

In a similar example, Capen et al. (1994) compared the mapping resolution used by a Gap analysis project in Vermont (100 ha pixels) to a finer scale resolution that mapped stands to an average size of 9.5 ha. They found that with the finer scale resolution there were 68 community types on a 62,000-ha study area that were analyzed with species habitat models to support 98 bird species. Using a similar analysis with the Gap data, 56 of the 68 community types were "lost" and only 67 of the 98 bird species were retained. Thus, too coarse a scale of resolution can lead to different and often misleading results of both available ecosystems and associated species.

On the other hand, using data at too fine a scale can overwhelm data storage and analysis capabilities for most planners. One landsat thematic mapper scene (185 km × 170 km) for 7 bands at a 30 m pixel resolution requires 244.3 megabytes of computer memory (C. Campbell, Boise Cascade Corp., pers. comm.). With current technologies leading to capabilities of a 1-m pixel resolution, with potentially 900 times the data generation of a 30-m pixel, the data support needs can become staggering. As computer speed and data handling and storage capabilities expand, these barriers may disappear. At the present, however, real limitations of hardware and software relative to the planning landscape area exist and must be recognized.

Another example of resolution delineation was discussed by Schneider (1994: 27). He stated "The length of the seacoast as measured on a map will differ from that measured by pacing along the beach because the map measurements are at a much coarser scale than pacing. The customary view of this difference is that the beach has a true length and that measurement with a meter stick is closer to the true value than measurement with a larger unit, such as a kilometer stick. But how far do we take this? Should we say that measurement with a meter stick is also inaccurate, and that a centimeter stick must be used instead? How small a stick is necessary to obtain the "true" length?"

For stand delineation or measurements, similar decisions must be made. Fine-scale data, such as a 1-m pixel resolution, theoretically can distinguish a 1-m gap in canopy coverage in a stand of trees. Should all of these gaps be mapped out as separate stands? For most purposes, this would present too fine a resolution of a landscape to interpret relative to mapping of "homogeneous" stands. At some fine scale of resolution, additional precision may be greater than that discerned by a species of interest, if a fine filter assessment is being utilized. For example, it is very unlikely that an elk (*Cervus elaphus*) would respond to a 1-m gap in canopy coverage. However, a vole (*Microtus* spp.) might select a 10-m patch of grass in an understory. What then is appropriate, mapping of 10-m gaps, 50-m gaps, 1-ha openings, or 5-ha openings? The larger the discontinuity in the vegetation that is accepted, the greater will be the variance around parameters for descriptions of stands. The finer the resolution, the more homogeneous the overall stand delineations, up to a point where additional precision is actually sampling variation within otherwise homogeneous stand conditions.

The concept of minimal area of a stand (Mueller-Dombois and Ellenberg 1974, Barbour et al. 1980) has considerable relevancy to this resolution question. Thus, resolution of data and mapping precision are critical considerations in classifying and describing ecosystem management landscapes. The specific use of the classification will help to identify an appropriate resolution. The resolution of data and mapping is usually set by what is available within a planning budget, with little consideration given to the assessment or consequences of using the selected scale.

Resolution considerations also operate for temporal components of ecosystem management. In monitoring or data collection, the sampling intensity or interval should consider the periodicity of the process or phenomena being sampled or monitored. For example, measurement of humidity in riparian zones in the Western United States reveals more variability on a hourly basis (Fig. 2) throughout a day, than variation from different locations at any one point in time (R. Danehy, Boise Cascade Corporation, pers. comm.). Thus, investigations of factors influencing humidity in riparian zones would need to account for the temporal changes in humidity throughout a day in any meaningful analysis of site effects. Similarly, habitat use by many animals is strongly influenced by daily activity patterns. Beyer and Haufler (1994) displayed how failure to monitor habitat use throughout a 24-hour

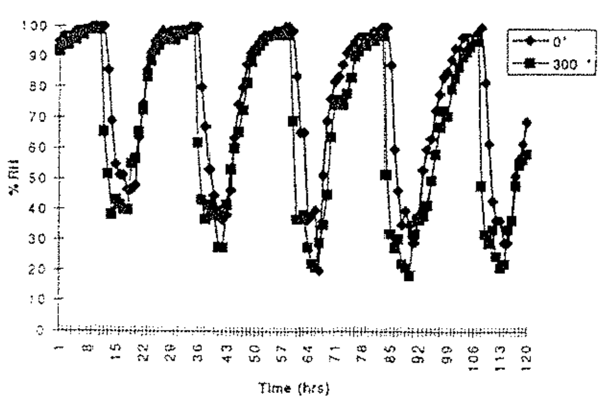

Fig. 2. Graph of relative humidity (RH) recorded hourly at two distances from a stream in Western Oregon. R. Danehy, Boise Cascade Corporation, unpublished data.

time-span for animals that are both diurnally and nocturnally active can lead to inaccurate descriptions of habitat use and importance. At a different temporal scale, vegetation structure, composition, nutrient status, and other factors change seasonally, and even within a season, as plants grow and senesce. These temporal patterns may not be consistent even in fairly local environments depending on influences such as elevation, aspect, shade, and soil moisture. At a longer temporal scale, the vegetation being sampled will change annually with growth and maturation of stands, and successional change. At longer time scales, differences have been noted between ecological time and evolutionary time. Schneider (1994: 28) distinguished these as "Evolutionary time operates on a longer time scale, over which changes in gene frequency can be described as trends, rather than a noisy coming and going of alleles. Ecological time operates on a shorter time scale, over which changes in population size occur with little or no change in gene frequency." The significance of all of these temporal effects on the information being collected by the sampling or monitoring should be considered in sampling designs.

4.3 Time-spans for Future Planning

Maintaining biological diversity and ecological processes involves considering time frames that are often far beyond traditional planning horizons. Genetic components of biological diversity may involve the analysis and planning for multiple generations of a species to assure that adequate heterozygosity of gene pools are maintained. Such time frames are beyond the practical realm of resource management decisions, yet ecosystem managers must factor these long-term concerns into the planning process.

Another example of the importance of temporal scales in ecosystem management involves the exchange of genetic information and provisions for demographic and environmental stochasticity among metapopulations of a species. Noss and Cooperrider (1994) and Harris and Gallagher (1989) discussed the importance of maintaining corridors that allow connectivity of similar habitat, such as old growth, to facilitate dispersal and genetic interchange. They felt that this was important to avoid problems with inbreeding or stochastic population fluctuations that could disrupt or extinguish metapopulations. This concept views the landscape as a static condition, where metapopulations are continuously linked by corridors of similar habitat condition. Old growth corridors would provide connectivity among late successional stands in a landscape, assuming animals used the established corridors, but they would also isolate earlier successional stands in the landscape, as it is impossible to provide connectivity of all late successional dependent metapopulations and early successional metapopulations at the same time. While dispersal capabilities of old growth dependent versus early successional dependent species have not been extensively examined, metapopulation considerations point to the importance of addressing all connectivity concerns. By incorporating a temporal scale into the plan, connectivity of diverse populations at appropriate time intervals to protect against inbreeding concerns can be factored into the plan. Camp et al. (1997) and Oliver et al. (1997) discussed a landscape analysis that showed dynamic shifts over time of refugia for early or late successional species, and that through changing landscape configurations, connectivity of all metapopulations can be achieved. Thus, temporal considerations can provide critical linkages in landscape planning designs.

Another consideration for the planning time-span is the duration of the planning horizon relative to the duration of the disturbance regimes of the primary ecosystems in the planning landscape. As mentioned previously, return-intervals for fire disturbance can range from less than 25 years to over 1000 years (Agee 1993). Tides cycle more frequently than daily. Major flood events may occur at very irregular cycles, but aquatic ecosystems may take hundreds of years to recover. Planning for 1000 years is unrealistic from a pragmatic management standpoint. Yet, the significance of 1000-year disturbance intervals should be factored into ecosystem management plans for such ecosystems, without overlooking the importance of the more frequent, often less severe, disturbances.

At very long time-spans (i.e., >1000 years), the effects of shifts in species ranges, and climatic events such as global warming or cooling, could produce changes in species interactions and competitive advantages, and change the basic composition and structure of ecological communities. Some would use such information to argue that any attempts to characterize or classify ecosystem compositions, structures, or distributions are inappropriate. However, the necessity of providing a reasonable projection of ecological outputs from a planning activity overrides these broader temporal scale views of ecosystem dynamics.

4.4 Historical Time-span Considerations

Perhaps less ominous but equally challenging is defining an appropriate historical perspective to use in ecosystem management. To meet ecological objectives, understanding historical ranges of variability can provide important reference points. However, what range of variability is being defined? Human alteration of natural disturbance regimes has been dramatic over the last 100–200 years. Even prior to this, indigenous populations were significantly influencing ecosystems to varying degrees. With some disturbances occurring at intervals of 500+ years, range of variability can become intermeshed with shifting species distributions and climatic changes, as discussed above.

Ecosystem management must factor in an understanding of the influences of historical disturbances on the occurrence, structure, and functioning of component ecosystems in the landscape, and understand the relationship of these historical disturbances with recent anthropogenic disturbance. Each landscape must be evaluated as to the appropriate reference timeframe for an understanding of historical disturbance regimes. In the Western United States, an historical perspective might focus on a time-span of 100–400 years ago (Steele 1994). In the Eastern United States, because of the earlier extent of dramatic anthropogenic influences, the appropriate time-span for analysis and quantification may be from 200–400 years ago.

Incorporating historical perspectives into ecosystem management has severe restrictions from availability of data. Typically, forests in drier landscapes have preserved more stumps and logs that can be used for dendrochronology studies, but in wetter environments, sources of data may be very restricted. Morgan et al. (1994) discussed sources of information on historical disturbance regimes.

5 SCALE RECOMMENDATIONS

All efforts at ecosystem management at a landscape scale are new approaches, and as such, should be viewed as experimental and adaptive programs. This is not to imply that landscape approaches are not based on the best available information, or that they are in any way inappropriate management directions, but rather, that their results should be monitored and adjusted as needed. Scale recommendations fall directly into this category. Little empirical data exist as a direct basis for designating appropriate scales. However, various recommendations can be proposed that may serve as initial targets for adaptive management.

The extent of an ecosystem management initiative needs to balance the various objectives and constraints, as discussed previously. The section level or aggregates of sub-sections within Ecomap (1993) seems to be a reasonable balance of minimum size to meet ecological objectives with a maximum size to maintain an acceptable amount of variability in ecological communities and to involve partnerships and data compilation. Terrestrial components, such as cells within an ecosystem diversity matrix (Haufler et al. 1996), should have acceptable levels of variance at this scale, with most of the biodiversity of the landscape occurring in maintainable populations. Aquatic components should also be able to aggregate to this scale, with watersheds as one level of identifiable units that can aggregate up to the landscape level (Bailey 1996). This extent of a landscape should also allow data to be collected and analyzed at resolutions that are sufficiently fine-grained to meet the needs of fine filter assessments.

Resolution of maps and data collection should be detailed enough to meet the desired objectives, but allow for compatibility with available storage and analysis systems. Landsat imagery at 30-m pixels can meet the needs of many objectives, but may not be detailed enough for some fine filter assessments. It also lacks the ability to discern many kinds of information that may be needed in ecosystem management including understory characteristics, soil typing, and stream classifications. Stands should be mapped at resolutions that provide sufficient description of community and habitat features to allow for all components of biodiversity to be accounted for. If resolutions are too coarse, then components of biodiversity can slip through the heterogeneity of stand conditions in the mapping, and ecological objectives may not be met. Even mapping resolutions of 5–10 ha will not typically identify many small or linear habitats, such as narrow bands of riparian vegetation. Such linear habitat may be the primary habitat of species such as the previously mentioned yellow warbler. Too detailed a resolution may not allow functional homogeneous units to be mapped in a landscape. The appropriate mapping resolution for a planning activity must be carefully evaluated relative to the full suite of management objectives. If the desired level of resolution cannot be obtained at present due to budget or technological limitations, then the potential implications of this should be clearly identified and stated.

Planning time-spans should recognize degrees of expectations at increasing time intervals. Relatively detailed plans are often expected for the immediate future (e.g., 10 years). Less detailed plans, that still prescribe specific targeted conditions and their locations on the ground, might be expected for a 20–50-year horizon. Plans for longer than 50 years tend to portray trends for the conditions that need to be present, and descriptions of how they will be provided, but not to the same degree of specificity as for the shorter time frames. The realization that demands, knowledge, and technologies will undoubtedly change dramatically over the next 20 years makes unrealistic the expectation that detailed plans will remain in effect for long time periods. For longer time periods, it is probably more reasonable to target ecological conditions that are expected to be needed to meet ecological objectives, and assure that short-term plans provide for the capability of providing these conditions in the future. Thus, plans should strive to meet short-term specific objectives, and assure that longer-term objectives are not precluded.

Historical perspectives of ecosystem management are well summarized by Morgan et al. (1994). They felt that the historical ranges of variability of significance to ecosystem management should be "assessed over a time period characterized by relatively consistent climatic, edaphic, topographic, and biogeographic conditions" (1994: 94). For inland forests in the Western United States, Steele (1994) recommended a time interval of 100–400 years for defining historical disturbance regimes. In other areas this time interval may need to start further back to factor in the earlier influences of European settlement.

6 CONCLUSIONS

1. Scale considerations are a critical component in all ecosystem management efforts, and include the extent of the planning landscape, the resolution of mapping and data collection, the time-span for the planning horizon, and the time-span for an historical perspective.

2. No one scale will meet all objectives of ecosystem management. Rather, appropriate scales must be selected for the various objectives, and linkages among these scales identified.

3. Analyses at different scales, or at the same scale but in different landscapes, can lead to significantly different conclusions. Thus, many ecosystem management relationships are scale and/or landscape dependent.

4. The spatial extent of planning landscapes must be large enough to address adequately population viability, biodiversity, and other such components of ecological objectives, but not be so large as to cause either too much variance in delineated ecological communities within the landscape, or make infeasible the building of collaborative partnerships or databases. The section level of Ecomap (1993), or aggregates of subsections, may be an example of this balance.

5. The resolution of mapping and data should be detailed enough to allow for the identification of landscape mapping units (e.g., stands, stream reaches) that can provide descriptions of the habitat requirements of species, but allow for a reason-

able identification of homogeneous conditions for planning. Pixel sizes of 30 m, or mapping resolutions of approximately 2 ha may balance these needs for many landscapes, although all management objectives need to be evaluated relative to the planned resolution. Data and budgeting restrictions may preclude a desired level of detail, but desired levels of detail may be targeted for future efforts.

6. Planning time-spans should focus on providing detailed actions for short-term objectives, while also providing for conditions to be produced or maintained to meet long-term objectives. The duration of successional trajectories and disturbance regimes must be factored into planning time-spans.

7. Historical perspectives must address time-spans that allow for historical disturbance regimes to be considered prior to dramatic anthropogenic alteration, but balance this with the length of time that data on these disturbances can be generated. In the inland forests of the Western United States, a 100–400-year perspective may be appropriate (Steele 1994).

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