MODELING FOREST LANDSCAPE CHANGE IN THE OZARKS: GUIDING PRINCIPLES AND PRELIMINARY IMPLEMENTATION

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Abstract: Although research and management approaches for ecosystem management have been troublesome to define, we believe a number of guidelines can be used to focus research. These include: (1) synthesize the extensive information describing hardwood ecosystem response to disturbance, (2) ensure that syntheses cross traditional boundaries between disciplines and resources, (3) develop principles that operate at the broad scale and avoid getting mired in excessive detail, (4) incorporate a modeling framework to organize information and relationships, and (5) focus on mechanisms of disturbance. Disturbance is a normal, ongoing process in Central Hardwood ecosystems. It takes many forms, but among the most extensive are weather damage, fire, and harvest and regeneration practices. Much is already known about how Central Hardwood forests respond to disturbance, but this knowledge is too poorly organized to allow us to explore the impacts of disturbance at the landscape scale. We present a structured framework for organizing and modeling ecosystem attributes (and their change over time) in Central Hardwood landscapes. The model is based on the premise that forest vegetation communities follow patterns of development that, although highly variable, have central tendencies that can be predicted through time with reasonable accuracy. After a vegetative community is altered by disturbance, it eventually resumes a characteristic (often highly stochastic) pattern of development. Although vegetation characteristics are dynamic in time, they are spatially anchored. Knowledge of the vegetation condition at a given place and time allows us to associate other ecosystem attributes that can be estimated from vegetation conditions (e.g., economic value, wildlife habitat suitability, scenic beauty). For a large forested landscape, a suitable minimum scale of analysis is the stand, typically about 5 ha in size with boundaries that often coincide with physiographic features. Patterns at this scale can be aggregated and analyzed to evaluate ecosystem attributes that operate at larger scales. Tools to facilitate this procedure are already available or can be adapted to the task. We recalibrated the LANDIS model for the species and conditions in the Missouri Ozarks and used that model to simulate landscape change through time. We demonstrate the model showing simulated patterns of disturbance and vegetation response for a small Ozark forest landscape.

INTRODUCTION

In the past several years, increasing emphasis has been placed on understanding the ecological implications of management activities at landscape scales. This movement has been evident in public land management agencies, and the USDA Forest Service has taken a particularly active role. This shift in emphasis from managing individual stands to managing mosaics of forest stands for multiple resources within a landscape has met with some confusion both in terminology and in implementation. "New Perspectives" and "Ecosystem Management" have been two of the widely used monikers to describe this initiative. In the Forest Service, some initiatives appear destined to have a short life span or limited scope from the outset; others catch hold and lead to fundamental changes. From our view, the ecosystem management initiative falls into the latter group.

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Nevertheless, the whole concept of ecosystem management has resulted in considerable head-scratching on our own part as we considered the following questions:

What does ecosystem management mean in the Central Hardwood Forest complex?

How does it differ from the management practices that are already in place, many of which already embrace some of the concepts embodied in ecosystem management?

What type of research is necessary to address issues surrounding ecosystem management?

What, if anything, can we contribute to this initiative?

In this paper we address these questions and several others as we describe our path to a better understanding of ecosystem management and ecosystem management research in Central Hardwood forests.

SEEKING A DEFINITION OF ECOSYSTEM MANAGEMENT

The initial problem with ecosystem management is one of definition. Arriving at a working definition is essential, but all definitions of ecosystem management are vague or at least nonspecific. A common refrain is "I can't describe ecosystem management, but I know what it is when I see it."

One formal definition of ecosystem management from the USDA Forest Service (1994) is the following:

> *Ecosystem management is not an end in itself, but a means to achieve sustainable conditions and provide wildlife and fish habitat, outdoor recreation, wilderness, water, wood, mineral resources, and forage for society while retaining the esthetic, historic, and spiritual qualities of the land.*

Note that the initial focus of this definition is on what ecosystem management is *not* rather than what it is. This simply underscores the fact that it is easier to identify those things that clearly are not representative of ecosystem management than to succinctly define those that are.

Another Forest Service definition of ecosystem management is that of Bartuska (1993):

> *Ecosystem management means using an ecological approach to achieve the multiple-use management of national forests and grasslands by blending the needs of people and environmental values in such a way that national forests and grasslands represent diverse, healthy, productive, and sustainable ecosystems.*

A third definition is that of Thomas (1996):

> *Simply stated, ecosystem management is the integration of ecological, economic, and social factors in order to maintain and enhance the quality of the environment to meet current and future needs. It is a holistic approach to natural resource management. To use it, we must step back from what foresters call the stand level and focus on the broader landscape.*

He notes that ecosystem management is in keeping with the multiple-use mandate of the Forest Service, but is more inclusive in terms of characteristics evaluated, larger spatial scales, and longer time frames.

Despite some inevitable degree of ambiguity in the definition of ecosystem management, several characteristics are consistently associated with the concept: (1) ecosystem management maintains diverse, healthy forest ecosystems; (2) it stresses sustainability; (3) it blends needs of people and environmental values by including people as an integral part of the ecosystem; (4) it considers effects at multiple spatial and temporal scales; (5) it addresses uncertainty and risk; (6) it emphasizes monitoring and evaluation; and (7) it employs adaptive management techniques.

"It's having and using a lot more information about much larger areas"[4] is among the more practical definitions of ecosystem management that we have heard. Although this definition is decidedly nontechnical and nonspecific, it captures the essential elements of large landscapes and multiple values.

[4] From Bill Sexton, Deputy Director of Ecosystem Management, USDA Forest Service, Washington, DC.

RESEARCH OPPORTUNITIES

We could make excellent progress with ecosystem management research in the Central Hardwood region if we could select an ecosystem, say a large watershed, and answer the following questions:

— If we apply a particular management practice, what is the impact on ecosystem integrity or health?
— If we apply a particular management practice, what is the impact on ecosystem sustainability?
— If we apply a particular management practice, what is the impact on ecosystem productivity?

Unfortunately these questions hide other more fundamental questions. Namely:

— What is ecosystem integrity or health, and how do we measure it?
— What is sustainability, and how do we measure it?
— What is productivity, and how do we measure it?

Faced with this degree of intractability in defining research issues, we had to narrow our consideration to research that is both possible and practical. In our discussions of ecosystem management research, we have concluded that synthesis of existing information is essential. We will never have perfect knowledge about ecosystem composition, structure, and function. Consequently, there is no need to wait for the completion of some definitive study before we start drawing conclusions relevant to ecosystem management. In fact, we already have vast knowledge about many aspects of forest ecosystems. For example, literally thousands of publications deal with oak silviculture. More than 250 publications address growth and yield in the Central Hardwood forest. The base of published literature for eastern old-growth forests exceeds 700 articles (Nowacki and Trianosky 1993); for savannas, the body of published literature consists of more than 450 items[5]. Paul Johnson[6] has termed this wealth of knowledge "an embarrassment of riches" relative to hardwood forest management. Despite this abundance of literature, what we collectively understand about hardwood forests is poorly organized for addressing the issues of ecosystem management in the Central Hardwood region. Specifically, much of what we understand about forest vegetation dynamics is limited in geographic scope and in spatial scale (e.g., to stand-level relevance). Linkages across resources or disciplines such as silviculture, economics, growth and yield, recreation, scenic preference, wildlife, and water quality are generally weak. Linkages across spatial scales are typically even weaker. Linkages from processes that operate at large scales (e.g., large mammal movements, fire or wind disturbance, regional economic health, water quality protection) to those that operate at relatively small scales (e.g., the vast majority of contemporary silvicultural practices) are central to ecosystem management.

Several principles have guided and prioritized our venture in ecosystem management research. First, for reasons outlined above, we believe that one of the most productive ways to begin in the Midwest is to synthesize what is already known about these forests. This includes synthesis for multiple resources: vegetation, wildlife, aesthetic quality, economic value, recreation, and water quality.

Second, syntheses must cross the traditional functional lines of silviculture, wildlife, economics, recreation, and other relevant disciplines. The scope of this work requires a cooperative effort.

At a fine level of detail, this synthesis has the potential to become overwhelming. Consequently, a third guiding principle is to seek the big picture at the landscape scale before getting mired in site-specific details. A landscape is " a heterogeneous land area composed of a cluster of interacting ecosystems" (Crow 1991). Obviously, there is considerable latitude in defining the spatial extent of a landscape, but landscapes encompassing tens to hundreds of square kilometers are typical. In the Midwest, this is an appropriate scale for integrated, multiple-resource forest management and for assessment of cumulative effects (both spatially and temporally).

Fourth, some sort of a modeling framework is essential. There are simply too many components to handle in any other manner. Modeling has the added advantage (if carefully designed) of allowing us to begin by formalizing general principles and processes and then adding site-specific details as they become necessary to address specific management issues.

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[5] Personal communication, Alan Rebertus, School of Natural Resources, University of Missouri, Columbia, MO.
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Finally, midwestern hardwood ecosystems have been continuously shaped by disturbance. Disturbance is a normal ongoing process. Consequently, predicting changes in ecosystem attributes in response to disturbances is a necessary prerequisite for resource management. Generically, a disturbance is any temporally discrete event that disrupts the structure, resource availability, or physical environment of a population, community, or ecosystem (White and Pickett 1985). Three disturbance factors that have great historical and contemporary importance in the Central Hardwood region are wind, fire, and timber harvest. Other factors such as insects and disease are of great importance in certain localities. For a specific, limited set of disturbance processes, we must answer the question for a real ecosystem, "How will this ecosystem respond to any given sequence of disturbance events?" More specifically, we must focus on those ecosystem attributes for which we have some knowledge and that are relevant to management decisionmaking. For a given ecosystem, this leads to the researchable questions: "How do attributes of vegetation composition, vegetation structure, wildlife habitat quality, economic value or aesthetic quality change over time in response to disturbance?"; "How are those changes spatially arranged on the landscape?"; and "What are the implications of those changes and tradeoffs that are relevant to management decisions?"

SCALE

All definitions of ecosystem management incorporate the concept of evaluating impacts at multiple scales. But what scales are appropriate? By definition an ecosystem can be as small as a drop of water or as large as the biosphere. Our ability to develop linkages across this range of scales is nonexistent in the foreseeable future, so what scales are essential? Silvicultural treatments in midwestern forests (and hence harvest disturbances) are prescribed for individual stands (roughly 5 ha). Thus, the finest scale must be at least this small. On the other hand, ecosystem management incorporates landscape-scale considerations.

From a practical perspective, relevant landscape sizes are typically on the order of tens to hundreds of square kilometers. The largest scales are dictated by a combination of administrative, ecological, and technical factors. National Forests in the Midwest are organized into ranger districts or administrative units that may be as large as 100,000 ha. From an ecological perspective, large-scale management planning may be best conducted within ecologically similar units termed subsections (McNab and Avers 1994, USDA Forest Service 1981). These may be hundreds of square kilometers in size. Additionally, an analysis unit ideally should be several times larger than the home range of the important animals that live in the unit.

There are two major technical limitations at the large end of the scale. One is the capacity of computing technology to model, analyze, and display information on large tracts. Although often constraining at first glance, computational capacity is almost never a limitation of consequence. In the length of time it takes to develop and test a landscape-level model, limitations in computing capacity that appear constraining at the start of the project are inevitably eliminated by subsequent technological advances in hardware and software. The technical limitation of greater consequence is finding a landscape-level data base suitable for model development and application. If, for example, projections of change across a large landscape are to be based on current vegetation composition and structure, site quality, topography, and historical patterns of wind, fire, and harvest disturbances, then all those attributes must be known or predictable across the entire landscape. There are few places in the Central Hardwood region where such detailed, spatially explicit databases exist.

Fortunately, there are two such data bases in the Ozarks of southeastern Missouri. They are associated with the Mark Twain National Forest (approximately 105,000 ha) and the Missouri Ozark Forest Ecosystem Project (3,725 ha) (Brookshire and Hauser 1993). These areas have detailed spatial data with layers describing topography, ecological land type, and current vegetation spatially referenced in a geographic information system (GIS). In addition, the ongoing Ozark/Quachita Highlands Assessment will provide more extensive information at an even larger scale.[7] This region is characterized by a predominantly forested landscape that is interrupted by clearings for pasture in the major stream and river bottoms (Figure 1). Annual harvest is approximately 40% of growth and less than 1% of the standing inventory (Leatherberry 1990). Harvest is principally by the selection method (either by silvicultural group-selection or individual-tree-selection or by "logger's choice" selection).

[7] Cooperative project by Forest Service Regions 8 and 9 and the North Central and Southern Forest Experiment Stations.

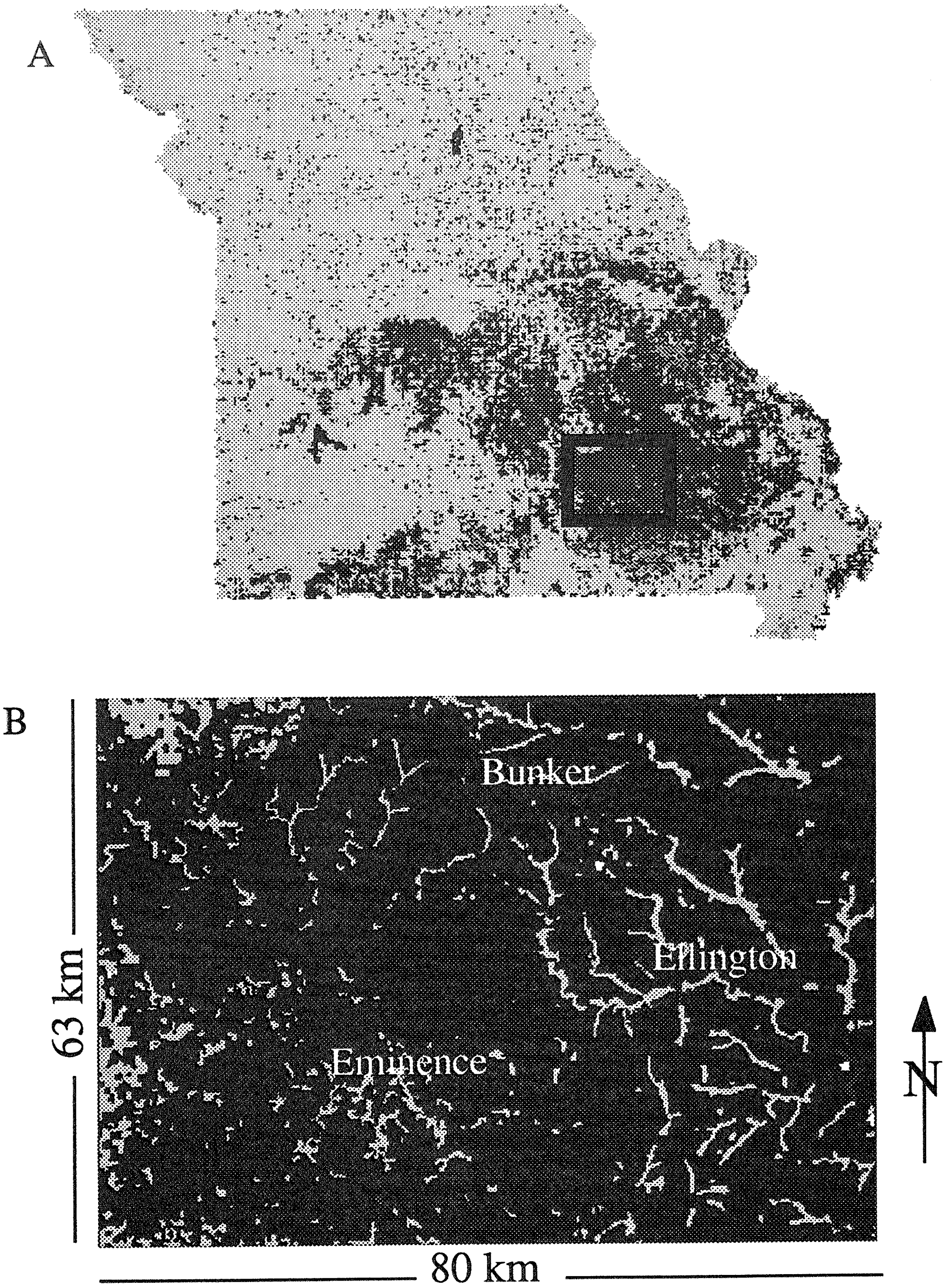

Figure 1. (A) Missouri forest cover showing general location of mapped forest landscapes amenable to detailed analysis and simulation. (B) Characteristic view of vegetation cover in southeast Missouri Ozarks. The area is predominantly forested (dark shading) with interspersed agricultural lands (light shading) that are virtually all pasture.

Fire is a dominant factor shaping the vegetation of the Ozarks, but the nature of fire disturbance has changed over time. Before European settlement (1580-1820) the mean fire-free interval was approximately 12 to 18 years. Between 1821 and 1940 the mean fire-free interval had decreased to 4 years (Guyette 1995). In the years since then, the major impact of fire has come from its exclusion rather than its presence. Wind, also, is a disturbance factor that shapes these forests through the creation of both small and large openings in the forest canopy. Mean return intervals for non-catastrophic wind events in the Ozarks are on the order of 260 years[8], but tornadoes (26 per year in Missouri) add to wind disturbance.

PREDICTING LANDSCAPE CHANGE THROUGH TIME

Our goal in this research is to predict change in landscapes at spatial scales as large as a few hundred thousand hectares while tracking details for individual, mapped stands as small as a few hectares. From this we can estimate and contrast changes in an array of ecosystem attributes that result from alternative disturbance (i.e., harvest, fires, wind) regimes.

We make the following assumptions in our model:

1. Changes in vegetation composition and structure follow predictable patterns of development and respond in predictable ways to disturbance.
2. The landscape can be divided into ecologically similar units that have similar patterns of vegetation development and similar disturbances.
3. If we know (or have predicted) vegetation composition and structure for a mosaic of stands at a future point in time, we can say significant things about other ecosystem properties including those that operate at larger spatial scales (e.g., wildlife populations, economic value, aesthetic quality, product yields, landscape structure, biological diversity).

Fortunately, the implementation of this process in the Missouri Ozarks can draw on a number of existing technologies and research tools. The general idea of projecting landscape change has been prevalent since GIS became a practical tool for forest management in the late 1980's. Since that time the practicality of landscape scale simulation has increased markedly as spatial analysis software has improved, computing power has increased, and characteristics of forest landscapes have been incorporated into spatial (GIS) and information databases.

Also, software to simulate vegetation change in response to natural disturbance patterns has been developed for other regions (e.g., Botkin 1993, Jones and others 1995, Mladenoff and others 1996). The LANDIS model (He and others 1996, Mladenoff and others 1996) is well-suited for adaptation to the Missouri Ozarks. LANDIS characterizes a landscape as a mosaic of square "sites" or pixels. Each site is geographically referenced (mapped) and identified with a specific ecological land unit. Vegetation at each site is represented by a dynamic list of tree species cohorts present by age class. Stochastic equations predict changes over time in the number of cohorts by species and age class at a given site. Predicted changes at a given site respond to the presence or absence of wind and fire disturbances. Wind and fire disturbances are represented as spatially explicit stochastic events on the landscape. The frequency and size of those disturbance events can be altered to investigate different ecosystem responses. We have calibrated LANDIS for the 16 most common tree species and 7 generalized ecological land types adapted from the Forest Service ecological land classification guide for the Missouri Ozarks (USDA Forest Service 1981). We are in the process of developing techniques that will realistically simulate the disturbance of harvesting and that will incorporate linkages from vegetation at each site to other ecosystem attributes (e.g., wildlife habitat, regional economic value, aesthetic quality, product yields, landscape diversity, biological diversity).

Several examples of implementation of LANDIS in the Missouri Ozarks illustrate our approach. We started with a mapped landscape showing ecological land units (Figure 2). This landscape consists of 839 ha (Compartments 7 and 8) of the Missouri Ozark Forest Ecosystem Project (Brookshire and Hauser 1993). This landscape was subdivided into 9,323 30 m-by-30 m sites (or pixels) for simulation with LANDIS (He and others 1996, Mladenoff and

[8] Personal communication, Alan Rebertus, School of Natural Resources, University of Missouri, Columbia, MO.

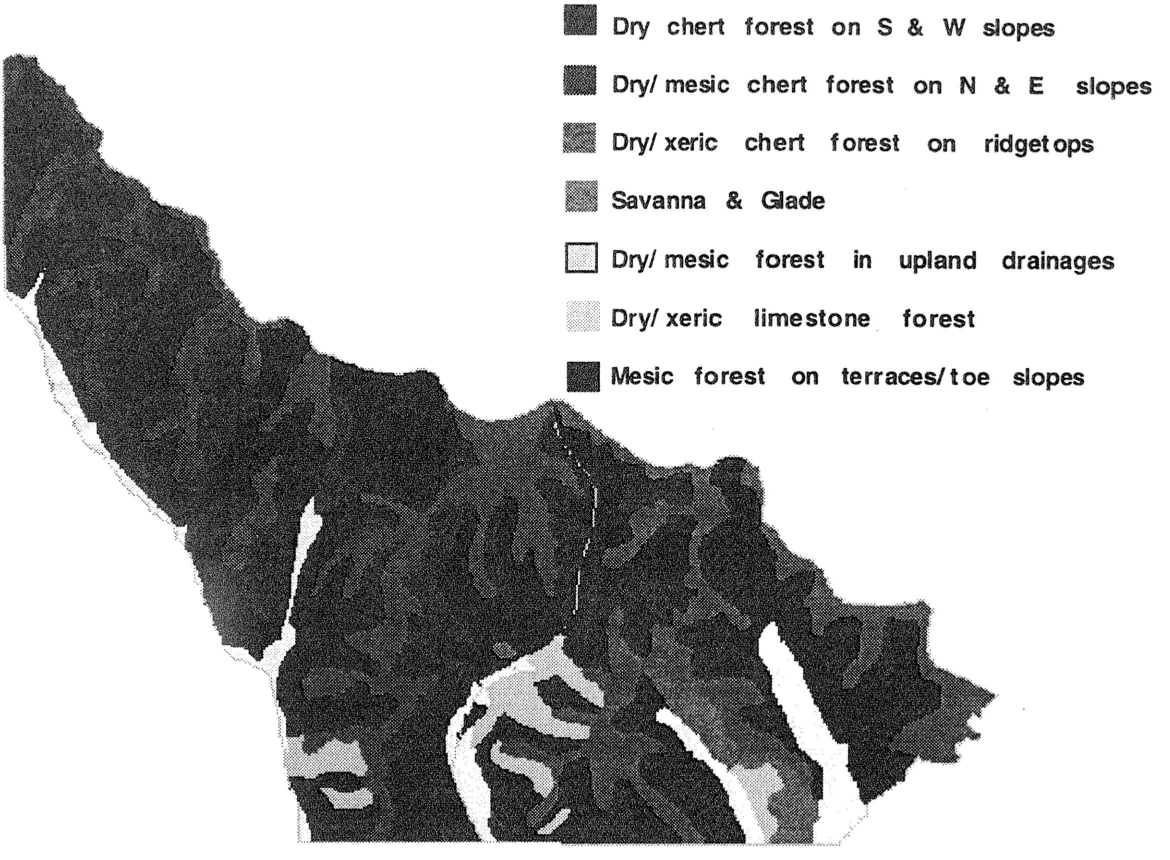

Figure 2. Missouri Ozark Forest Ecosystem Project (MOFEP) Compartments 7 and 8, Carter County, Missouri. Ecological land units are based on USDA Forest Service (1981).

others 1996). We simulated change in vegetation composition and age structure and the effects of fire and wind disturbance on patterns of development.

We compared fire disturbance events at two frequencies (Figure 3). The low frequency fire regime had a mean return interval of approximately 100 years. The high frequency regime had a mean return interval of 4 years, approximating fire frequency in the Ozarks from 1821 to 1940 (Guyette 1995). We plotted cumulative wind disturbance over a century (Figure 4) as the summation of simulated wind events with random spatial coordinates and with a size distribution of events corresponding to estimates of large-scale wind events in southeastern Missouri. The results in Figure 4 are based on a mean event size of 5 ha and a mean return interval of 260 years, values that are characteristic for the Missouri Ozarks.

The tree species and age classes associated with each site changed in response to the presence or absence of disturbance events. We displayed species information in several different ways. The maximum age of trees by site can be displayed at any point in time (Figure 5). We also mapped the distribution of dominant species (Figure 6). Although Figures 5 and 6 are illustrations for one point in time, the values at each site change each decade in the course of a simulation and can be thought of as a moving picture through time. The presence or absence of individual species can also be tracked through time over the course of a simulation. For instance, we displayed the presence and absence of white oak and red maple on the simulated landscape at two time periods 50 years apart (Figure 7).

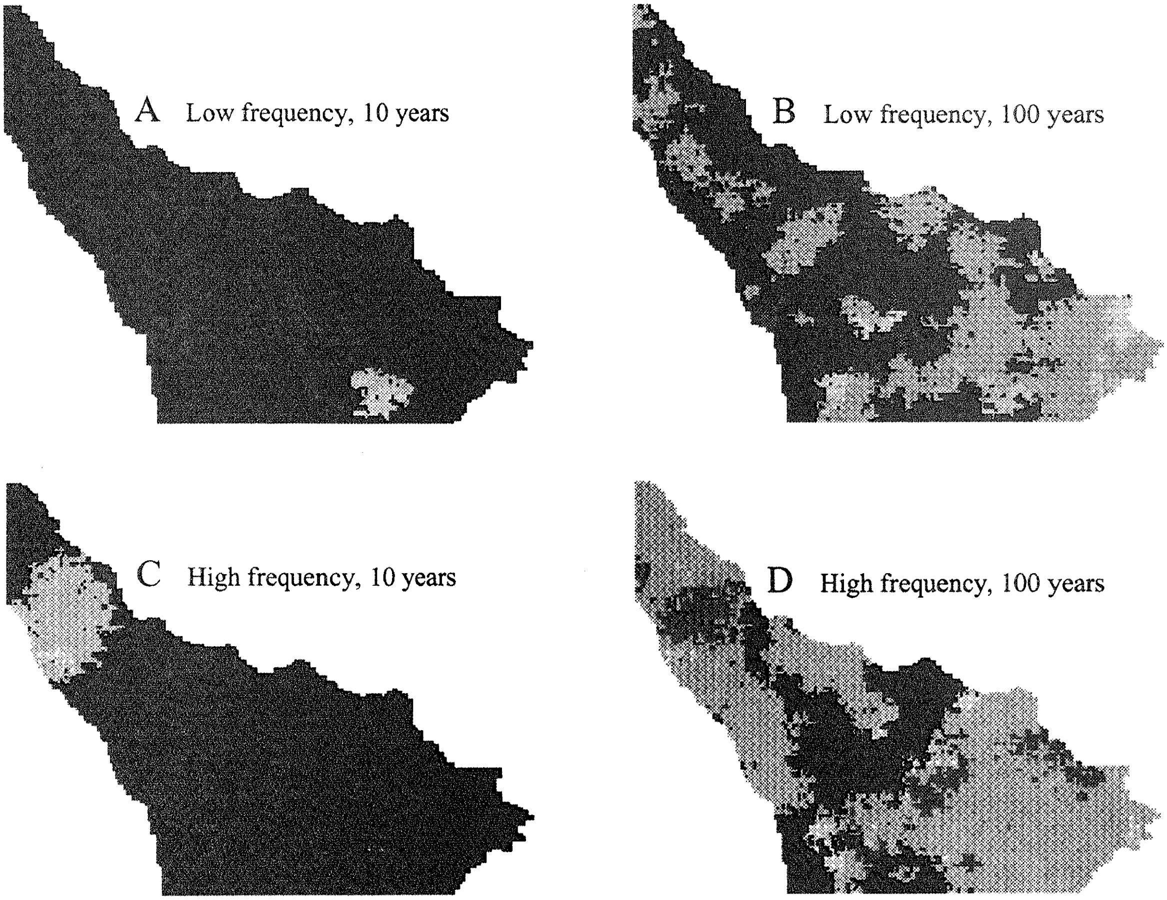

Figure 3. One hundred years of simulated fire disturbance on MOFEP Compartments 7 and 8. Lighter shades indicate disturbance. Accumulated burned area per century is 40% in panel B and 70 percent in panel D

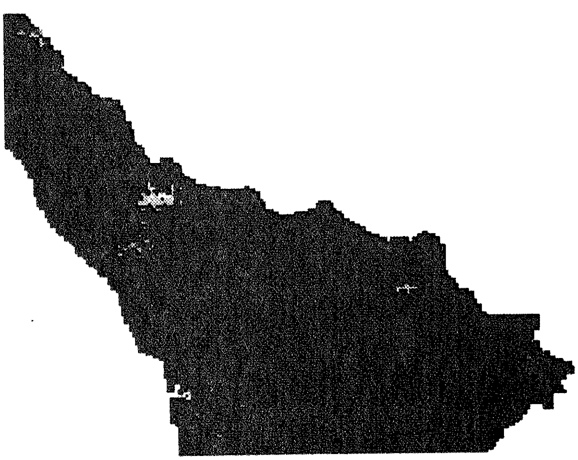

Figure 4. Cumulative simulated wind disturbance over a century. Lighter shades indicate wind disturbance.

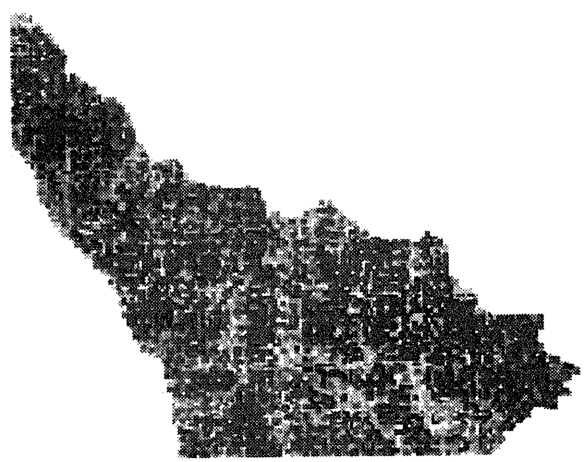

Figure 5. Snapshot in time of simulated age distribution for LANDIS applied to MOFEP Compartments 7 and 8. Darker sites have young cohorts; lighter shades indicate older cohorts.

While Figures 3 through 7 illustrate some of the capabilities and limitations of the modeling approach, model validation is a necessary step prior to large-scale applications. Long-term, spatially explicit databases that would allow direct comparison of model predictions with field observations simply do not exist. However, several sources of information can be used to evaluate model performance. These include minimally disturbed old-growth forests, a few managed forests with known disturbance histories spanning 5 decades, and opinions of foresters and ecologists with extensive experience in the region. Validation and fine-tuning of coefficients is ongoing.

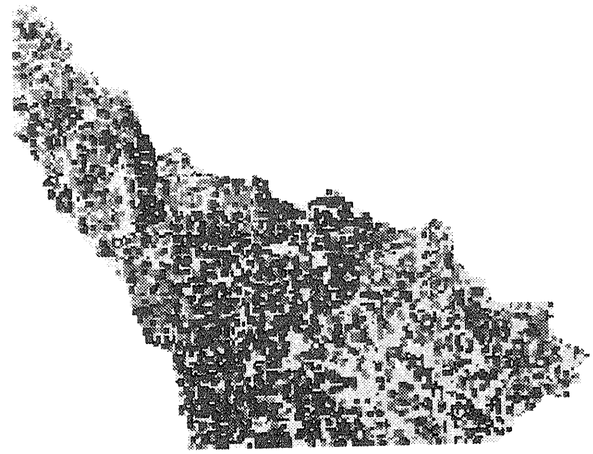

Figure 6. Snapshot in time of dominant species for LANDIS simulation. Shades of gray indicate differing dominant species cohorts

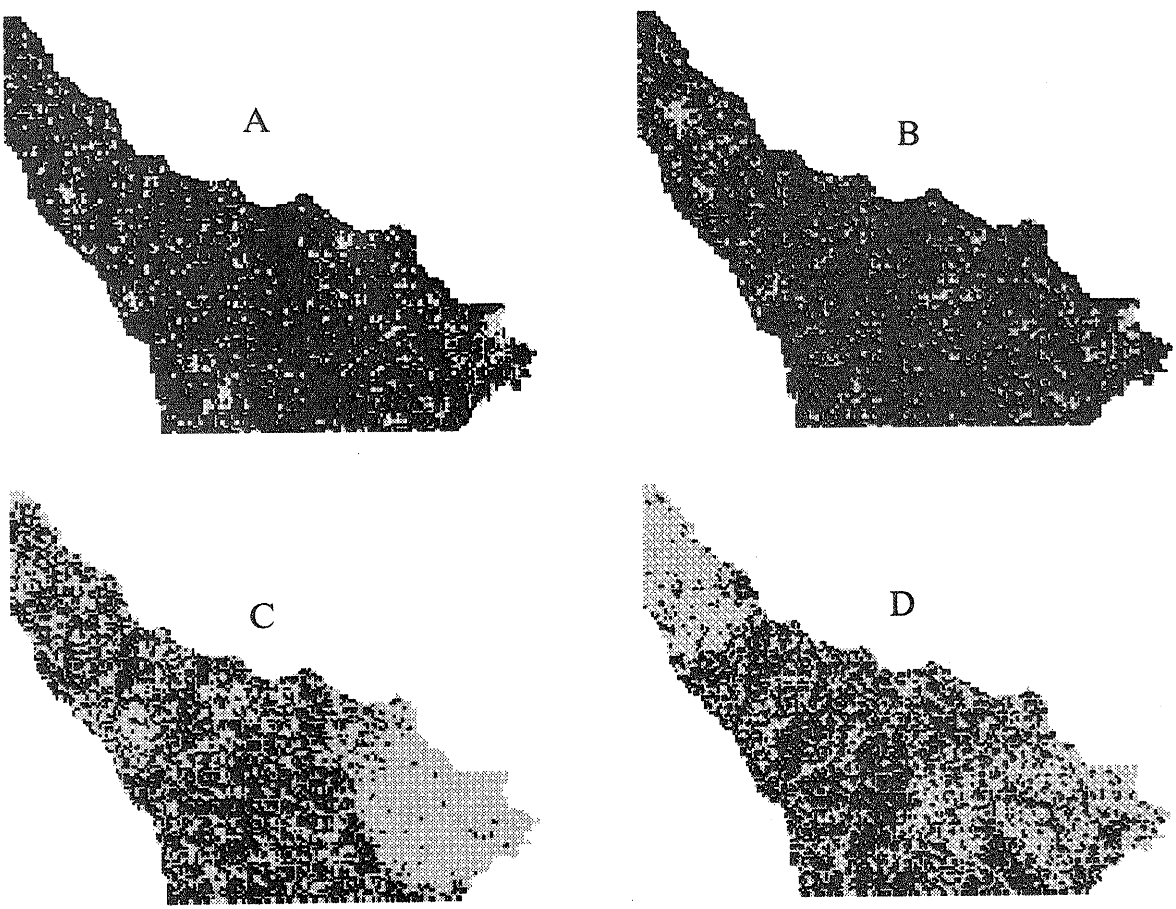

Figure 7. Presence of white oak and red maple species cohorts by site (pixel). Panels A and B show presence (dark sites) of white oak at two times separated by 50 years of simulated change. Panels C and D show presence (dark sites) of red maple for the same sites and time periods. Simulated fires have reduced the presence of red maple in the lower right corner of panel C and the upper left corner of panel D while showing little impact on white oak in panels A and B.

CONCLUSIONS

We believe it is important for research in support of ecosystem management in the Central Hardwood region to (1) synthesize the rich body of knowledge relevant to Central Hardwood ecosystems; (2) include syntheses that cross the functional lines that have often separated foresters, ecologists, economists, sociologists, and soil scientists; (3) incorporate a modeling framework to organize information; and (4) focus on the big (landscape) scale before getting buried in the site-specific details. The complexity of this research requires a team of cooperators.

Disturbance by fires, harvest, and wind is the norm, not the exception, in Central Hardwood landscapes. Vegetation response to disturbance is at least partially predictable, and many other ecosystem attributes of interest at the stand and landscape scale can be predicted from knowledge of the vegetation composition and structure. Consequently, models that focus on simulating spatially explicit response to disturbance can be useful tools for dealing with the issues inherent in ecosystem management. We anticipate that for maximum utility, such models must be capable of dealing with landscapes as large as 100,000 ha.

Our initial parameterization of the LANDIS simulation model for conditions found in the Missouri Ozarks illustrates the type and format of information contained in landscape models. The technique provides a mechanism for modeling vegetation change through time and predicting response to fire and wind disturbance. The model must be modified to simulate harvest disturbance, but we believe that tools of this kind have the capability to give us a better long-term, large-scale picture of the impacts of disturbance on forest landscapes.

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