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USEFULNESS OF SPATIALLY EXPLICIT POPULATION MODELS IN LAND MANAGEMENT[1]

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Abstract. Land managers need new tools, such as spatial models, to aid them in their decision-making processes because managing for biodiversity, water quality, or natural disturbance is challenging, and landscapes are complex and dynamic. Spatially explicit population models are helpful to managers because these models consider both species–habitat relationships and the arrangement of habitats in space and time. The visualizations that typically accompany spatially explicit models also permit managers to "see" the effects of alternative management strategies on populations of interest. However, the expense entailed in developing the data bases required for spatially explicit models may limit widespread implementation. In addition, many of the models are developed for one or a few species, and dealing with multiple species in a landscape remains a significant challenge. To be most useful to land managers, spatially explicit population models should be user friendly, easily portable, operate on spatial and temporal scales appropriate to management decisions, and use input and output variables that can be measured affordably.

Key words: habitat model; land management; landscape ecology; resource management; scale; spatial model.

WHY SPATIAL MODELS ARE NEEDED IN LAND MANAGEMENT

Natural resource managers today are faced with new challenges that differ from previous ones in both their emphasis and scope. In the past, resource management was based on the philosophy of sustained yield of one or more products such as timber, game, recreation, or grazing units (Behan 1990). Multiple use of lands was achieved by providing one service or commodity on one parcel of land and another service or commodity on another parcel. Little consideration was given to the interactions between activities on individual parcels. However, due to increasing concerns about local and global ecological problems, public land managers have had to reorient their emphasis toward conservation of functional ecosystems (Behan 1990, Kessler et al. 1992). Maintaining biodiversity, water quality, and aesthetic values are considered as important as providing products such as timber on the same parcels of land. Maintaining a natural disturbance (e.g., fire) regime may also be a goal in the management of some public lands. However, managing for biodiversity, water quality, or natural disturbance necessitates a regional or landscape perspective (Noss 1983, Turner 1989, Hornbeck and Swank 1992). Instead of perceiving the landscape as several independent parcels, managers must deal with the entire landscape and begin to anticipate how activities in one area might affect the physical and biotic properties of adjoining areas. In addition, both ecological and economic analyses for different resources within the same geographic area are likely to

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be required. Because landscapes are both complex and dynamic, land managers will need new tools, such as spatial models, to aid them in their decision-making processes (Behan 1990).

It is difficult to conduct a full set of experimental studies to understand species' responses to management at the landscape scale. It may be logistically impossible to conduct controlled experiments with large-scale manipulations in natural areas, although ongoing land management or natural events (e.g., the 1988 fires in Yellowstone) offer unique research opportunities. In addition, replicating large-scale experiments or sampling regimes is often prohibitively expensive, and it is unlikely that a large manipulation in a natural area could be replicated to obtain a statistically satisfying sample. Even if treatments could be repeated, pseudoreplication remains a potential problem. However, stochastic simulations with a model can be replicated many times and the results summarized statistically, thereby providing an estimate of the range of potential effects. Thus, modeling allows the manager to explore the implications of events for which landscape-level experiments are not feasible. This paper examines the potential contributions of spatially explicit population models to land management issues, features that will make the models most useful to managers, how the outputs from the models can be used in land management, and limitations to the use of this type of model.

Advantages of Spatially Explicit Population Models

Habitat suitability models have been the primary tools available for the management of noncommodity populations such as threatened and endangered species (e.g., Verner et al. 1986). Habitat suitability models attempt to prescribe the range of habitat conditions that will provide all the requirements for a particular species. However, these models do not incorporate the spatial dynamics of species–habitat relationships (Walters 1992). The actual existence of a species in an area, its ability to reach adequate habitat, and its response to locational changes in habitat are usually not included. Because wildlife populations are mobile, and dispersal is often a critical stage in the life history of many species, the spatial arrangement of habitats across the landscape is essential to both understanding the ecology of the species and effective management.

In contrast to habitat suitability models, spatially explicit population models consider both species–habitat relationships and the arrangement of the habitats in space and time (Dunning et al. 1995), going far beyond simple comparisons of suitable and unsuitable habitat. Thus, these models can address questions of fragmentation, isolation, habitat shape, and patch size, providing the manager with a tool to determine not only what types of habitats are needed, but also how these habitats should be arranged across the landscape. Furthermore, potential effects of no management, alternative management strategies, or natural events can be examined. For example, following the 1988 fires in Yellowstone National Park and some calls for prescribed burning within the Park, a model was developed to explore the effects of scale and pattern of fires on wintering elk (*Cervus elaphus*) and bison (*Bison bison*) populations in northern Yellowstone Park (Turner et al. 1994). Because these are simulation models, they provide the manager with a tool to determine what management schemes will best achieve the desired conditions. The models can be used to evaluate how the species in question will be affected either directly or indirectly by management activities that change the spatial or temporal (e.g., age class structure) configuration of the landscape or increasingly fragment what had been contiguous habitat (e.g., Franklin and Forman 1987).

Spatially explicit models provide a variety of outputs that are useful for managers. Spatially explicit simulations are often accompanied by visualizations that allow the manager to "see" the effects of alternative management strategies, often in real time as the simulation progresses. The power of visualization should not be underestimated, as a picture may be worth 1000 graphs in explaining a model simulation to a land manager. However, numerical outputs remain useful because managers are often target oriented (e.g., oriented toward maintaining a minimum population size or aiming for a particular rate of increase) and may need to defend their decisions in courts. Wildlife biologists often must rely on numerical values because they may compete with other resource needs in an attempt to maintain minimum populations (e.g., forest timber production vs. species conservation). Models that integrate ecological and economic components so that the models can be used to explore both sets of consequences simultaneously are even more valuable. For example, ECOLECON, which incorporates the economics of timber production and the ecology of a potentially threatened species (Bachman's Sparrow, *Aimophila aestivalis*) in Southeastern pine forests (Liu 1992, 1993), allows managers to balance the sparrow population size and the economic outputs from timber production.

Spatially explicit models may be particularly useful in developing a robust relative ranking of management alternatives. This is especially appropriate for the more general "top-down" models, which represent types of organisms in a general fashion but are not predictive for a particular species (see O'Neill et al. 1988, Turner et al. 1993, Pearson et al., *in press*), but is also relevant for species-specific models (e.g., McKelvey et al. 1992). Alternative management strategies can be evaluated and ranked in terms of the risk they pose to the species, i.e., a probabilistic output, rather than as a prediction of what will certainly occur. Results from complex spatial simulations also might be reduced to simple rule-based systems that are easily understood and applied by managers. For example, results from a large set of simulations of the Northern Spotted Owl (*Strix occidentalis*) model might lead to the following management guidelines: (1) for a given total area of habitat, bigger patches are better than smaller patches up to a particular threshold size (R. H. Lamberson et al., *unpublished manuscript*); and (2) patches of old growth that are close together will provide better genetic mixing than patches that are isolated.

Limitations of Spatially Explicit Population Models

The use of spatially explicit population models must not be perceived as a panacea for land managers. As with all models, these models are only as good as the data upon which they are based, and the lack of data for the scales or area of interest may be an important factor limiting widespread implementation of spatial models. Accurate and up-to-date data bases, generally within a geographic information system (GIS), are required, and this can be an expensive undertaking. Not every organization will find it cost effective to move from a paper-and-file based method of storing information to a computer-based system, although the benefits of transferring information to a digital form have been well documented. Further, extensive field studies may be required to parameterize a model for a given species in a given landscape and to monitor the success of the model in making predictions.

Once developed, spatially explicit models may be constrained by both the resolution and extent of the model. Although it is possible to develop rules that permit the extrapolation of data or predictions across scales (Turner et al. 1989), this may not be straightforward. Therefore, it may not be possible to directly transfer a model parameterized for a resolution of 1 ha to another system with greater or lesser spatial resolution. While this is not an intractable problem, both modelers and managers must be aware of the scale constraints imposed by a particular model formulation.

Dealing with multiple species in a landscape remains a significant challenge for spatial models, and the relevance of these models to the conservation of biodiversity is not yet clear. Most spatially explicit models to date have been developed explicitly for one or a few species (e.g., Northern Spotted Owl, Bachman's Sparrow, elk, and bison) and are only appropriate for those species. Extrapolating from single-species models to "biodiversity" is problematic. One approach would be the development of models for selected indicator species, which are frequently used as surrogates for biodiversity, but this approach is not without controversy. As an alternative method of maintaining native animal diversity, some scientists have proposed examining presettlement vegetation patterns as a template (Thomas et al. 1990) and reintroducing or allowing natural ecological processes to perpetuate native vegetation dynamics (Hejl 1992). In the absence of models for each species of interest, the development of spatial models of vegetation changes over large landscapes could assist managers seeking to maintain the diversity of wildlife and other species.

Management Examples

We know of two spatially explicit models that are actually being used by land managers to aid the decision-making process. A model for Spotted Owl dynamics (McKelvey et al. 1992) has been used by the Bureau of Land Management (BLM) to evaluate the effects of a series of potential land management plans for BLM lands in western Oregon on Spotted Owl populations during the next 100 yr. The BLM developed a series of six plans representing a variety of cutting intensities and prescriptions. The plans were formulated using standard harvest optimization models, but the cutting was portrayed spatially over time in a GIS. The habitat quality of the resulting vegetation patterns was then evaluated by overlaying a 1000-ha hexagonal grid on the landscape and quantifying the area of suitable owl habitat within each grid cell. In an initial assessment, the Spotted Owl model was executed using three alternative sets of rules for defining habitat suitability. The simulations were used to ordinally rank the land management plans rather than as a formal viability assessment.

On a much finer scale, a spatially explicit model of competitive dynamics between two plants, an aggressive exotic bush lupine (*Lupinus arborea*) and a native endangered dune plant, the Menzies' wallflower (*Erysimum menziesii*), has been used by The Nature Conservancy for managing the Lanphere-Christensen Dune Reserve in Humboldt County, California (R. H. Lamberson, *unpublished manuscript*). Management efforts focus on controlling the spread of the lupine and promoting the growth of the wallflower. A map is maintained of the location of all individuals of each species. The model is used to project the spread of the wallflower with alternative lupine removal strategies over a 2–3 yr time horizon. Simulation results are compared with the mapped species locations biennially, and the transition probabilities in the model are modified to improve performance.

Future Directions

Certain features must be incorporated into spatially explicit models for the models to be most useful to land managers. There is little likelihood that the model will be embraced if its predictions are unrealistic, the interface of the program too difficult to understand, or the data needs unrealistic. The models should be user friendly and easily portable to the computer hardware and software available. Ideally, the model should operate on temporal and spatial scales that are relevant to the scale of management decisions, although models also can serve the very useful purpose of identifying the scale most appropriate for certain management decisions (Dunning et al. 1995). Managers would like to understand the function of the models and must be informed clearly about the uncertainties and assumptions inherent in the model and its appropriate use (i.e., limitations must be clearly specified). The outputs from the models will be most useful if the managers can afford to measure the appropriate variables needed to run and test the model, and if the models are continually improved in response to new understanding (Conroy et al. 1995).

The use of spatial models in land management should not be limited in scope to lands under a single owner. Land ownership has a large impact on management decisions, and a useful contribution of spatially explicit models is the ability to explore the effects of management by various owners within a mosaic of public and private lands. For example, the importance of the habitat conservation areas for Northern Spotted Owls on public lands changes when the scenario includes a complete harvesting of private lands within the landscape. Where ownerships are diverse, the difference between owner goals can create challenges, even when all ownership is public (e.g., the Greater Yellowstone Ecosystem).

Land management decisions will continue to be made, whether or not spatially explicit population models contribute to decision-making processes. Spatially explicit models are likely to be used as management tools as they become available, but there is often a time lag associated with improved management styles or regulations. Communication between land managers and ecologists remains an important challenge, and spatially explicit models have the potential to create a common working framework. Because of the visual and geographic nature of the models, their appeal to both land managers and researchers may enhance communication. Ecologists should strive to make the models both available and useful because these models can address relevant questions of species–habitat relationships in space and time and offer new insights to landscape managers.

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