

# MODELING FRAMEWORK

Swihart, R.K., & J.E. Moore (eds)  
2004. Conserving biodiversity in  
agricultural landscapes. Purdue  
University Press. 336pp.



# MODELING INTERACTIONS OF PRIVATE OWNERSHIP AND BIOLOGICAL DIVERSITY

## An Architecture for Landscapes with Sharp Edges

*Robert K. Swihart and Norman A. Slade*

### CHAPTER OVERVIEW

Sharp edges between habitats characterize many human-dominated landscapes. We explore the potential functional importance of sharp edges in ecological and socioeconomic contexts. We also identify and review a conceptual dichotomy in characterizing landscapes, factors driving land-use change, consequences of land-cover change for organisms, and the scale-dependence of land-use decisions and ecological processes. Integrated, interdisciplinary modeling efforts are essential if we intend to reduce detrimental environmental impacts associated with human-induced changes in landscapes. We outline an interdisciplinary modeling framework for linking social and economic drivers of land-use decisions with their effects on biological diversity in human-dominated systems. The modeling framework is integrated within an idealized land-use planning structure and provides a means of quantitatively comparing the suitability of competing land-use scenarios at multiple spatial scales. By producing suitability scores, it also can provide input to multi-criteria decision tools for land-use planners. As an example, we demonstrate the potential role of this modeling framework in complementing ongoing social, economic, and ecological research in an intensively agricultural landscape dominated by private ownership, the upper Wabash River basin of Indiana. We believe that landowner participation within a collaborative context is a key to incorporating biodiversity into land-use planning.

*KEY WORDS—Agriculture, biological diversity, land-use planning, conservation, habitat edges, habitat fragmentation, land cover, private property, socioeconomic drivers, spatially explicit models*

## INTRODUCTION

From a biological perspective, landscapes are complex systems consisting of spatially heterogeneous mixtures of patch, corridor, and matrix elements (Turner and Gardner 1991; Forman 1995) and exhibiting spatio-temporal dynamics at multiple scales. Structure (spatial relationships of objects) and function (fluxes of energy, nutrients, and organisms) of landscapes are determined by interactions of organisms with biotic and abiotic components of the environment, socioeconomic factors that influence land-use decisions, and feedbacks that alter the strength of interactions, attitudes, or economies. Humans often alter landscape structure by imposing disturbance regimes that differ from those occurring naturally and by creating a matrix of altered habitat associated with sharp edges abutting other habitat. Understanding the interactive effects of human alteration of landscapes on biological diversity requires a quantitative, interdisciplinary approach in which the hierarchical nature of processes is explicitly addressed within a modeling framework (Werner 1999).

To be useful, models of landscape change should address the information needs of individuals entrusted with making decisions about land use. Specifically, modeling tools for evaluating ecosystem structure and function should provide land-use planning professionals and stakeholders with an opportunity to adopt, revise, or analyze land-use strategies that are most likely to satisfy individual and community goals while promoting sound stewardship of natural resources and the environments within which they occur. Successful development of such tools requires an understanding of the processes that shape a landscape's structure and constrain its functions, including interactions of factors and feedbacks within and between social and ecological systems. Conceptual and theoretical developments are needed to improve the realism of existing models and to link socioeconomic drivers of land-use change with their ecological consequences. The papers in this volume are intended to stimulate interest and provide guidelines and ideas for developing and enhancing modeling capabilities in linking human drivers of land-use change with implications for species persistence in agricultural landscapes.

In this chapter, we outline an interdisciplinary architecture of integrated, state-of-the-art models for evaluating the biodiversity consequences of human-induced changes in land use/land cover (LULC). The modeling architecture serves as a basis for the chapters that follow and provides a framework to address some of the information needs of natural-resource-based land-use planning. A key component of the architecture is the recognition of a dichotomy prevalent in the characterization of landscapes.

## PREVAILING LANDSCAPE GESTALTS

Landscapes typically are characterized either environmentally by the distribution and types of physical and natural resources they contain, or anthropogenically by the distribution and societal characteristics of people inhabiting the land base (Rollings and Brunckhorst 1999*a,b*). Both views of landscapes involve spatially nested hierarchies in which information is transmitted between levels (Figure 1-1) (King 1997; Werner 1999). Interdisciplinary research is the key to conceptually unifying and comprehending the socioeconomic and ecological relationships that collectively define landscape structure and function; in turn, interdisciplinary activities hold the greatest promise for addressing applied problems associated with landscapes, including identifying alternative land-use options and prescribing limits or strategies for human development (Costanza 1996; Russell 1996; Costanza and Ruth 1998).

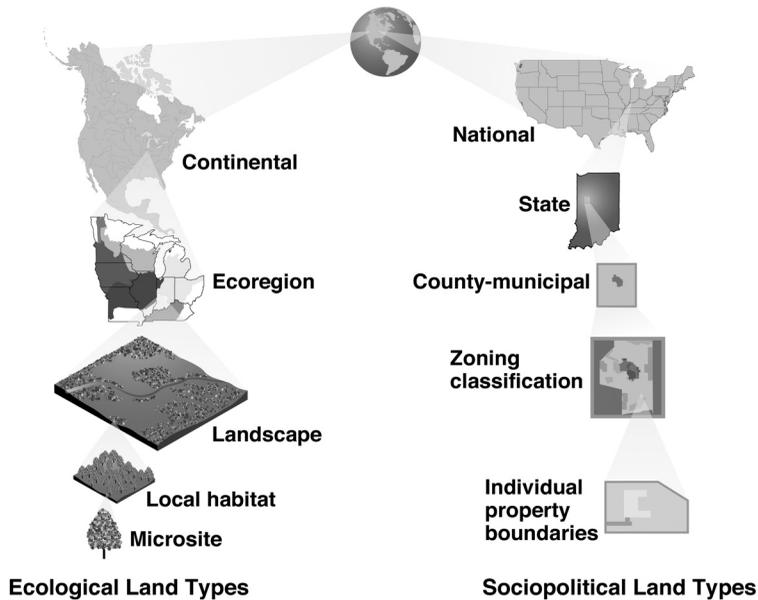


Figure 1-1. Both ecological and human views of landscapes result in nested hierarchies at spatial scales ranging from local to global. Interactions of sociopolitical and ecological land types often are ignored or oversimplified in models predicting attributes of biological diversity, even though social and economic forces often constitute the drivers of land-use change which affect species and their habitats. A color version of this figure is provided in the insert.

## DRIVERS OF LANDSCAPE CHANGE

Landscapes are spatially and temporally dynamic. Natural disturbances occur with varying levels of frequency and severity across a landscape, and changes wrought by disturbance subsequently affect processes within and among elements. The distribution and impact of a natural disturbance has a stochastic component (e.g., the location of a lightning strike) and a deterministic component (e.g., the predictable effects of fuel load and prevailing winds on the distribution and intensity of a fire caused by lightning), both of which contribute to the legacy of a disturbance (*sensu* Turner and Dale 1998) by altering landscape structure and function.

In human-dominated landscapes, anthropogenic disturbances are predominant drivers of physical and biotic changes (e.g., Saunders *et al.* 1991; Collinge 1996; Forman 1999; Crist *et al.* 2000). These disturbances are driven principally by societal and economic market forces, which ultimately respond to feedback from ecological processes (Farina 2000). Disturbances induced by humans include destruction and fragmentation of native habitat, urban sprawl, altered hydrological regimes, and pollution (Andersen *et al.* 1996). Farina (2000) referred to these areas of anthropogenic influence as “cultural landscapes.” As with natural disturbance, human disturbance often can be characterized by stochastic (e.g., the probability of an individual deciding to convert a property from agricultural to residential, or a political decision related to the location of transportation services) and deterministic (e.g., the predictable changes in land cover and surrounding property values resulting from such decisions) components.

## HABITAT ALTERATION AND SHARP EDGES

In terrestrial landscapes, several features of human disturbance differ from natural disturbance. A key difference is the extent and rate at which human disturbance can lead to fragmentation of native habitats. As a process, habitat fragmentation has two components, habitat loss and insularization (Wilcox and Murphy 1985; Noss and Csuti 1997). For instance, agricultural use of rural areas often results in fragmented patches of remnant vegetation embedded within an agricultural or residential matrix. Typically, habitat fragmentation leads to decreased remnant patch size, higher edge:interior ratios, increased patch isolation, and variation in the

degree of connectivity of patches (Harris 1984; Wilcove *et al.* 1986; Saunders *et al.* 1991).

Edge or ecotonal habitats in human-dominated landscapes typically are linear and exhibit sharp boundaries between adjacent vegetation or land-use types, rather than undulating, soft or gradual boundaries typical of many natural systems (Forman 1999). Thus, the structure of natural landscapes usually is transformed into a quilt-work series of disjunct patches or corridors of remaining natural habitat and a matrix of human landscape elements (e.g., agricultural fields, residential developments). Sharp edges characterize such a landscape and serve as the stitching between adjacent elements. Sharp edges arise from land-use practices and other human disturbances. For example, property boundaries may demarcate adjoining lands that differ markedly in land use. At larger spatial scales, sharp edges can arise at boundaries of municipal, county, or state jurisdictions as a consequence of legislatively mediated differences in land management.

Sharp edges affect a variety of ecological processes, including horizontal flow of nutrients and water, animal movement, and predator-prey or parasite-host interactions (Haddad 1999; Remer and Heard 1998). For instance, recent restoration efforts targeting coastal sage scrub in California have noted that transplanting shrubs can reduce sharp edge effects and improve habitat for California gnatcatchers, *Polioptila californica* (Bowler 2000). Experiments with artificial ground nests have demonstrated higher predation rates along sharp edges, suggesting that such edges serve as travel lanes for predators or as barriers to nesting birds (Ratti and Reese 1988). Physical alteration of marsh habitat resulting in sharp edges can lead to lower abundance of larval fish, suggesting that sharp edges also influence reproduction and recruitment in aquatic systems (Hendon *et al.* 2000). However, few attempts have been made to incorporate edge effects into spatial models. Fagan *et al.* (1999) used partial differential equations to construct an analytical framework within which the dynamical implications of edges for systems can be studied. Stamps *et al.* (1987) used simulations to show that the permeability of edges interacts with patch size and shape to influence animal movements in complex landscapes.

The previous examples highlight consequences of sharp edges resulting from human activities. Less attention has been paid to the social and political factors leading to the formation of sharp edges. A principal goal of two of the contributions in this volume (Bell *et al.*—Chapter 3; B. Miller *et al.*—Chapter 13) is to explore how differences in societal attitudes regarding land use, ecological processes, and aesthetics ultimately affect land-use practices, landscape composition, and the formation of sharp edges.

## ISSUES OF SCALE

Geopolitical edges span spatial scales from individually owned properties to state and national boundaries (Figure 1-1). Consequently, human-induced changes in LULC can lead to habitat patchiness at numerous spatial scales, which in turn can influence the movements and distribution of organisms. For example, animals may encounter resource patchiness (*sensu* Ostfeld 1992) at a broad scale during dispersal movements or at a fine scale during foraging within a home range. Of course, different organisms may perceive a given landscape at vastly different spatial scales (e.g., Zollner 2000). Regardless of scale, the sensitivity of animals to habitat fragmentation ultimately is related to their ability to move through the landscape, and this ability is related to a species' mobility, ability to avoid predation, competitive ability, and sensory capabilities for detecting and orienting toward suitable habitat (Fahrig and Merriam 1994). Dispersal events or interpatch foraging movements in fragmented landscapes often require travel through or around a potentially inhospitable matrix.

Responses of organisms to LULC also occur at numerous temporal scales. For instance, foraging movements of individuals occur at short time scales (e.g., ultradian or circadian), whereas dispersal often is a once-in-a-lifetime event. In extremely fragmented landscapes, dynamics of local populations tend to occur at a more rapid rate than for the set of local populations viewed collectively (Hanski 1998). Importantly, if the dynamics of landscape change are much more rapid than the dynamics of populations, species may exhibit lagged responses to landscape changes (Tilman *et al.* 1994). Under these circumstances, a species may be one of the "living dead," destined for extinction and present today only as a ghost of a prior landscape, rather than as an indication of an established equilibrium with the current landscape (ter Braak *et al.* 1998). Clearly, temporal and spatial scales of response both need to be considered when studying how organisms respond to changes in LULC.

## THE NEED FOR INTEGRATED MODELING OF HUMAN-DOMINATED SYSTEMS

In a recent review, Pickett *et al.* (2001) identified three opportunities for conceptual advances in understanding urban systems that we believe apply in general to human-dominated systems. These include (1) an integrated framework that deals with social and biological processes in a balanced fashion, (2) an appreciation of the potential importance of human-induced spatial heterogeneity on ecological processes, and (3) a reliance on the inherent

hierarchy of human-dominated systems as an organizing basis for spatial models and as the structural foundation for an integrated theory. Our modeling framework addresses each of these issues, as discussed below.

Land-cover change precipitated by humans is widespread. Conversion of natural habitats is occurring worldwide, with land principally being co-opted for agriculture or urban-residential development. Roughly two-thirds of the earth's terrestrial surface is used by humans for agriculture, pasture, or managed forests. In the United States, 121,000 km<sup>2</sup> of nonfederal land, an area 1.29 times the size of Indiana, were converted to urban development from 1982–1997 (Natural Resources Conservation Service, United States Department of Agriculture 1999). In the state of Indiana, native forest, prairie, and wetland habitats have been reduced over the past 175 years by 78%, 86%, and 99%, respectively, resulting in a high degree of fragmentation of remaining patches (Miller 1993; Hartman 1994). The net result of these human-induced changes is a considerable shift in the planet's natural and cultural capital. As human-dominated landscapes become more prevalent, understanding the socioeconomic drivers leading to land-use change and the ecological consequences of land-cover change takes on increasing importance for the conservation and management of natural resources (Collinge 1996).

Alteration and fragmentation of landscapes also can proceed in a social sense. For instance, privately owned nonindustrial forest land in the United States is being parceled into smaller pieces, with an estimated 1.2 million ha split into pieces of less than 40 ha every 2 years. Nearly 1 million ha of forest land also is being converted to development every 2 years (DeCoster 2000). Parceling of properties into smaller units can reduce levels of natural-resource management and increase heterogeneity of land uses; for example, family farms can become unviable due to subdivision among heirs, thus forcing their sale to unrelated individuals (DeCoster 2000; Sampson 2000). Urbanization and demographic shifts across the landscape also can lead to increased socioeconomic heterogeneity that affects land use. For instance, the rate of conversion of wildlands to urban uses has doubled in the United States during the 1990s; less than 6% of the area used for new housing previously was residential (Peterson 2000). Additionally, residential lot sizes have doubled and house sizes have tripled, even as the number of occupants per household has declined by about 25% over the last several decades (DeCoster 2000). In much of the middle portion of the United States, ownership patterns are highly fragmented, reflecting an urban-rural gradient characterized by small properties and high human density in or near cities and larger tracts of land with lower human density in rural areas. These gradients also may reflect differences among residents in their understanding of ecological roles of landscapes and attitudes toward land use.

Land-use changes leading to reduced area and connectivity of native habitat can impair ecological processes (Saunders *et al.* 1991), degrade watersheds (Montgomery 1999), constrain the manner in which land can be used (Bartlett *et al.* 2000), and thus ultimately threaten economic viability of landowners or communities. Land-use change, especially with respect to agriculture and forestry, has affected the central United States more severely than any other factor (Sala *et al.* 2000), and the rapid rate of fragmentation caused by urban sprawl has serious ecological, economic, and social repercussions (Friesen 1998).

Citizens increasingly are interested in how land-use decisions affect landscape structure and function. Of 459 ballot initiatives in the United States dealing with growth management and the preservation of open space during 1998–2000, 390 (85%) passed, resulting in a commitment of approximately 14.5 billion dollars to public land acquisition (Land Trust Alliance 2001). Local, state, and federal programs aimed at “smart growth” and “livable communities” are gaining visibility (Duany *et al.* 2002). Clearly, modeling efforts are needed that contribute to stewardship and conservation of land by addressing fundamental, process-based questions about the social and ecological dynamics of landscapes and subsequently formulating information into accessible decision tools that can be used by legislators, elected or appointed municipal officials, or other nonscientists in comprehensive land-use planning.

## Model Architecture

Ideally, land-use planning at the level of municipalities, townships, or counties results in proposed alternatives for land use (Figure 1-2; *see also* B. Miller *et al.*—Chapter 14). In reality, though, the relative suitability of land-use scenarios usually is assessed qualitatively or on the basis of expert opinions. Only occasionally are comparisons of competing scenarios contemplated, and these typically rely on a limited range of factors (e.g., “build-out” models; Lathrop and Conway 2001; Costanza *et al.* 2002) that seldom include consideration of biological diversity (*but see* Theobald and Hobbs 2002). Here, we describe a dynamic, spatially explicit modeling framework that integrates the social, demographic, and economic drivers of land-use decisions with their subsequent effects on ecological processes related to species viability (Figure 1-2). Our framework balances the treatment of social and ecological processes and addresses interactions within a dynamic, spatially explicit context that emphasizes the importance of anthropogenic habitat edges on ecological processes. Moreover, the spatially nested hierarchy of social and ecological systems is explicitly incorporated.

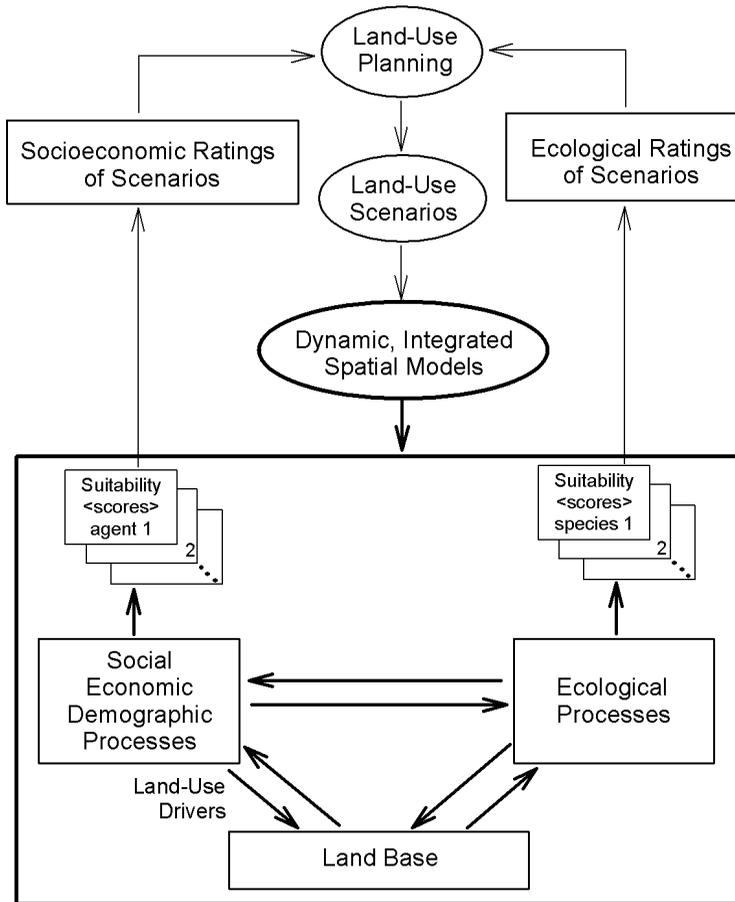


Figure 1-2. A conceptual diagram of an integrated modeling environment within the idealized framework of an iterative land-use-planning process. The portion of the diagram enclosed by the boldface rectangle details the integration of dynamic spatial models (indicated by the boldface ellipse). Arrows represent causal relationships and feedbacks between states. Vectors are indicated by  $\langle \rangle$ . Ratings are derived from the vectors of suitability scores and can be used in decision making.

The second component of the integrated modeling framework is a set of ecological models for predicting the effects of LULC change on the suitability of the landscape for species (Figure 1-2). Species differ dramatically in their mobility, energetic requirements, and niche breadth. Thus, a single class of ecological models is unlikely to be suitable for all species in a given landscape because perceptions of habitat patchiness or connectivity vary tremendously. Instead, we recommend a mixture of general patch-based metapopulation models, ecologically scaled landscape indices, and

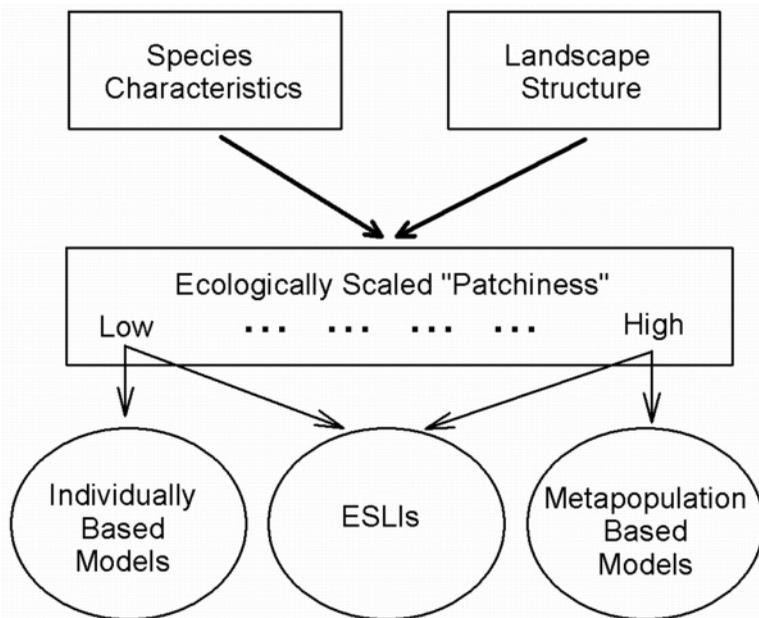


Figure 1-3. Outline of modeling approaches used for deriving the scenario-specific suitability scores depicted in Figure 1-2. For species that perceive a landscape as patchy only at the level of the individual (e.g., those with large area requirements and broad niches), suitability is indexed using individually based models. For species in which habitat patchiness is evident at the population level, suitability is indexed using metapopulation patch-occupancy models. ESLs are computed for all species.

complex individual-based models (Figure 1-3). Using land-cover maps produced in response to socioeconomic drivers, ecological models are applied to selected species representing a variety of life histories, dispersal abilities, and spatial requirements. A distribution of ecological suitability scores results for each species, with the model types determined by species-specific perceptions of landscape patchiness (Miller and Swihart—Chapter 7). Suitability scores can be used to evaluate alternative planning scenarios in terms of their impacts on individual species and assemblages. Detailed descriptions of spatial models (Feng and DeWoody—Chapter 4; Gu and Verboom—Chapter 5), ecologically scaled landscape indices (Swihart and Verboom—Chapter 6), and requirements for parameterization of individual-based models (Miller and Russell—Chapter 8; Moore and Russell—Chapter 11) are provided elsewhere in this volume. We believe that these tools are an important step to the inclusion of biodiversity considerations into the planning process (Crist *et al.* 2000).

Construction of an integrated modeling framework such as depicted in the lower half of Figure 1-2 requires three main components. First, multi-

scale socioeconomic models are needed to characterize human-induced land-use change occurring over a typical planning time frame (ca. 20 years). Understanding the spatio-temporal patterns of land-use decisions is critical to characterizing and predicting changes in the land base (Figure 1-2). Recognition of the human behavior underlying these decisions is of fundamental importance. A variety of empirical approaches have been employed to model land-use change (Agarwal *et al.* 2001; Plantinga and Irwin 2003; United States Environmental Protection Agency 2000; Veldkamp and Lambin 2001). Behavioral, economic, and demographic data from surveys, secondary sources, and the National Resources Inventory can be used to predict conversion of land to other uses, as discussed by Broussard *et al.* (Chapter 10). A review of prior efforts related to this component (Bell *et al.*—Chapter 3) and an exploration of parallels with ecological concepts (Bell and Slade—Chapter 2) are described elsewhere in this volume.

A third essential component in the integrated modeling framework has received less attention: linking socioeconomic drivers of land-use change with the ecological consequences resulting from land-cover change (*but see* Constanza *et al.* 2002 for an excellent example of linking economic and ecological models at the watershed level). Consider a geographic information system (GIS) characterizing land use in an area. Drivers from component 1 specify the probability of each raster “cell” (e.g., a pixel) in the area converting to another land use. Each land use has ramifications for land cover and thus habitat suitability at multiple scales. The changes in land cover induced by drivers from component 1 subsequently are used as input to ecological models for predicting the species-specific consequences of LULC change. The linkage between socioeconomic and ecological models is accomplished dynamically; transition probabilities for each cell can be updated yearly from the socioeconomic model and provided as input to ecological models via a spatially dependent Markovian process. The linkage component permits alternative planning scenarios to be simulated, producing base maps of land cover that enable comparison of the effects of competing scenarios on biological diversity. Craig *et al.* (Chapter 9) provide an indepth discussion of the linkage component of such an integrated model.

Outputs from the integrated modeling framework include ecological and socioeconomic vectors of suitability scores for each target species and selected human agents (e.g., ownership types), respectively (Figure 1-2). Suitability ratings can be used within a multi-criteria decision framework to enable comparisons of alternative scenarios. In an idealized planning context, comparisons should lead to additional scenarios and evaluations in an iterative fashion (van Mansfeld—Chapter 15). Changes in the land base feed back to affect subsequent decisions on land use, and changes in ecological processes feed back to impact human attitudes and the structure of the land

base. In the context of biodiversity considerations, the latter feedback typically operates on a longer time scale than the roughly 20-year period used in a comprehensive planning context, and thus is likely to be of minor importance in a planning context.

## Planning Tools

Ultimately, outputs from modeling frameworks such as the one in Figure 1-2 can provide decision makers with relevant information for assessing the impacts of proposed land-use changes on natural resources and society. Although increased attention is being given to the linkage between socio-economic and biological factors affecting an area's suitability for future development (Rollings and Brunckhorst 1999*a,b*; Liu 2001 and references therein), models addressing multiple factors largely remain inaccessible to a nonscientific audience. Modelers can contribute greatly in the land-use-planning process by providing sound information to decision makers in a user-friendly context (Theobald *et al.* 2000). A key characteristic of accessibility is the distilling of information at each successive level in a decision-making hierarchy (Figure 1-4). Accessibility promotes adoption,

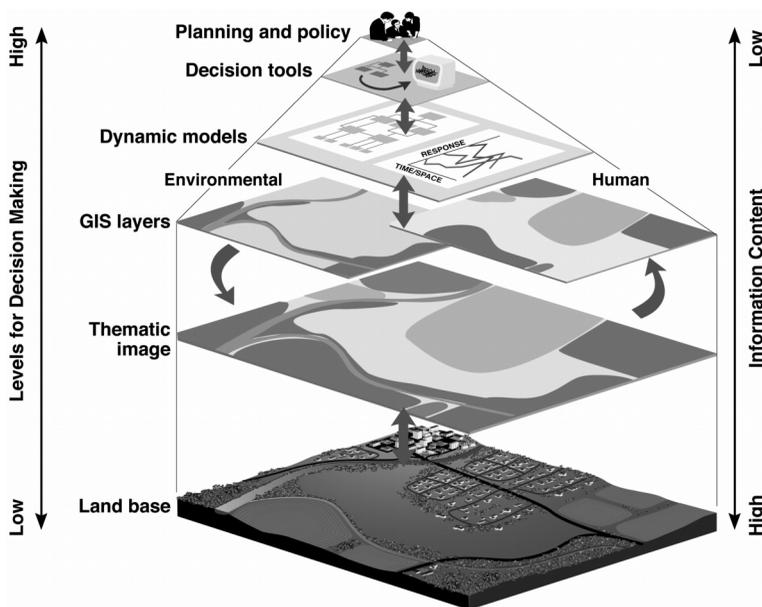


Figure 1-4. Schematic depiction of information levels used in land-use planning, and the distillation of information occurring at each level in the decision-making hierarchy. The modeling activities detailed in Figure 1-2 use information gathered at lower levels to produce integrated dynamic models, which subsequently are used in constructing multi-criteria decision tools. A color version of this figure is provided in the insert.

hopefully leading to more informed and forward-thinking planning decisions. An evaluation of obstacles to the use of models by planners, and rules to follow in constructing useful models, are provided by B. Miller *et al.* (Chapter 14).

By providing science-based information in a nontechnical, accessible format, modelers can enable decision makers to look at their community comprehensively, to consider the overall net benefits resulting from growth and land-use change, and to foresee the long-term tradeoffs and losses associated with accommodating growth. Many local planning officials have a limited understanding of the long-term effects of their decisions on ecological structure and function. Availability of modeling tools for evaluating ecosystem structure and function provides planning agencies with the opportunity to adopt, revise, or analyze land-use strategies that are most likely to satisfy personal and community goals while promoting sound stewardship of natural resources and the environments within which they occur.

We have focused on consequences of LULC change for species diversity because they are the ones most often neglected in land-use planning. Of course, comprehensive plans need to consider consequences for numerous human and natural systems, including economics, aesthetics, water quality, and biodiversity, to name only a few. Our decision-making paradigm (Figure 1-4) permits output from multiple modeling frameworks to be combined into multi-criteria decision tools. Often, local officials consider the fiscal impact of development, with little attention given to ecological impacts (Dale *et al.* 2000). Several single-criterion tools have been developed to assist decision makers in considering environmental or economic consequences of development, including conversion of prime farmland (Berry *et al.* 1996) or increased runoff (United States Environmental Protection Agency 2000). Unfortunately, examining a single environmental variable when considering land-use decisions fails to help planners weigh the tradeoffs between protecting multiple types of natural resources and achieving social or financial goals of the community. Our modeling framework can provide assessments of land-use consequences for ecological communities and community values (Figure 1-2). Other modeling frameworks exist for assessing consequences of land-use change on hydrology and non-point-source pollution (Harbor 1994; Bhaduri 1998; Schueler and Holland 2000), and fiscal impacts of human development (DeBoer and Zhou 1997). Collectively, outputs from these different frameworks provide a solid basis for multi-criteria decision-making within a GIS environment (*see* Crist *et al.* 2000; B. Miller *et al.*—Chapter 14).

One final point is worth noting regarding the application of our modeling framework as a planning tool. In complex landscapes, uncertainties are large and forecasting is difficult (Walker 2002). The framework we propose neither endorses nor encourages attempts to predict responses to specific land-use scenarios. Rather, our emphasis is on providing an environment

that supports multi-criteria decision-making by promoting comparison of alternative planning scenarios (*cf.* Kurz *et al.* 2000).

## From Models to Reality: Engagement, Infrastructure, Obstacles

Proactive planning that incorporates consequences for biodiversity (or other natural resources) can occur only when and where voters and elected officials accept its importance (B. Miller *et al.*—Chapter 13). Too often, planning and zoning decisions and the adoption of land-use controls tend to be reactive to changes occurring in a community (Rudel 1984). Instituting measures that address tradeoffs between development and conservation requires three complex and proactive steps by local officials: (1) identification of the critical natural resources in need of protection in their community; (2) determination of an acceptable balance of the community's social, economic, and natural-resource goals; and (3) the ability to craft comprehensive planning policies and land-use controls that will attain targeted goals.

Adoption of decision tools that incorporate environmental assessments can occur at numerous levels, from individual owners of small parcels to elected officials with influence over entire regions. The models developed and described in this volume are most applicable to master planning at the level of watersheds, townships, counties, or even basins. It is important to remember that in landscapes dominated by private ownership, individual landowners ultimately will drive decisions about land use and thus the role that biodiversity plays in the planning process. Land management, by necessity, will depend on collaborative, multi-owner stewardship. Moreover, because most comprehensive plans are developed by consulting firms, addition of an environmental analysis will increase the cost of planning exercises and thus must be justified to stakeholders and decision makers. We believe that the biodiversity-based models discussed in this volume can be used in conjunction with participatory activities (van Mansfeld—Chapter 15) to develop an increased awareness of the value of biodiversity and the importance of its inclusion in the planning process. For decision tools to have maximal utility, though, input should be sought from stakeholders during the formulation phase (Theobald *et al.* 2000).

Engaging stakeholders at an early phase provides modelers with the opportunity to draw on local knowledge, fosters enhanced communication and understanding between scientists and nonscientists, and increases the likelihood of subsequent adoption of decision tools. Stakeholders also are instrumental in assembling lists of alternative planning scenarios (Theobald and Hobbs 2002). The form in which modeling results are displayed also requires stakeholder involvement, because end users typically desire model

outputs that provide information about environmental conditions expressed in terms of combinations of indicators (Schiller *et al.* 2001).

Effective engagement is difficult without a well-developed infrastructure for delivering technical information to decision makers. It is imperative that the decision tool be based on the best available science, understandable, and user-friendly if it is to be used by local planners and other stakeholders. Here, we provide a brief overview of engagement activities and infrastructure for delivery of multi-criteria decision tools to stakeholders in the upper Wabash River basin of Indiana, closing with comments on the challenges and opportunities related to natural-resource-based planning efforts in landscapes dominated by private ownership.

## THE UPPER WABASH RIVER BASIN

The Wabash River contains the longest free-flowing riparian environment east of the Mississippi River. The location of the upper Wabash River basin (Figure 1-5) is notable because it encompasses a confluence of four major natural vegetation types tall-grass prairie, oak-hickory forest, beech-maple forest, and the southern perimeter of the Grand Kankakee wetlands complex; Petty and Jackson 1966) and thus provides a diverse array of options for studying human settlement patterns in relation to ecological boundaries (e.g., Bartlett *et al.* 2000). The juxtaposition of ecoregion boundaries in the basin also leads to a diverse fauna, making an informed selection of indicator species important for modeling purposes (Russell *et al.*—Chapter 12). Approximately 96% of the land in the basin is privately owned, which exceeds the average of 88% statewide (Birch 1996) and makes engagement for land-use planning purposes essential. Eighty-eight percent of the basin is in some form of agricultural land use (Figure 1-5). In addition, the basin provides a variety of demographic contrasts, including rapidly expanding cities and smaller communities with a dwindling population base.

## ENGAGING STAKEHOLDERS

Engagement of stakeholders occurs in several different forms in the upper Wabash River basin. Engaging Citizens as Stewards of Ecosystems (ECASE) is an interdisciplinary project at Purdue University merging discovery and engagement activities in the basin. The ECASE mission is to form partnerships with Indiana citizens, resulting in information on the distribution and

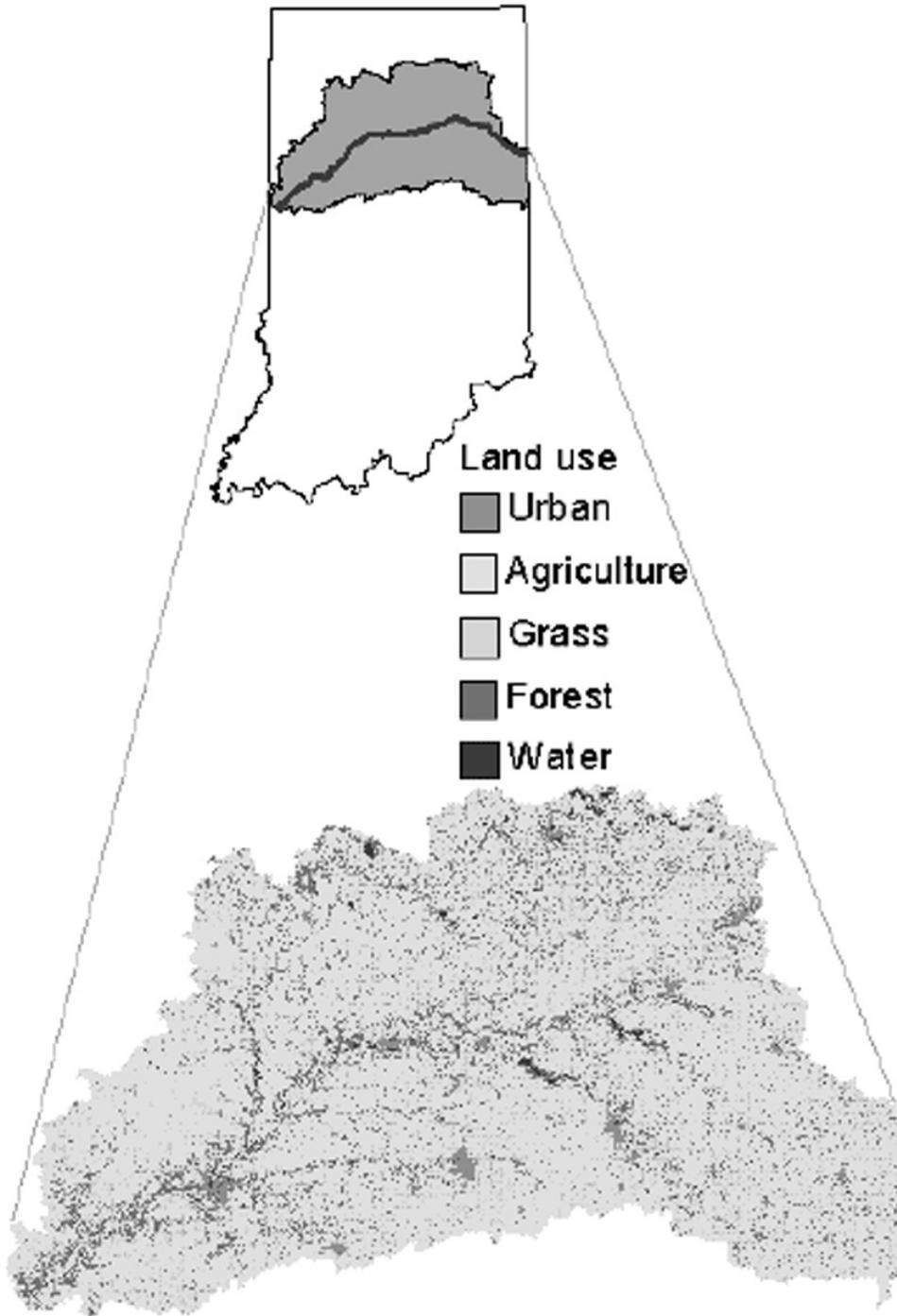


Figure 1-5. A map of Indiana showing the location of the upper Wabash River basin. The enlargement depicts the major land-use/land-cover types. The basin consists of  $>20,000 \text{ km}^2$ , draining  $>20\%$  of Indiana. A color version of this figure is provided in the insert.

roles of natural resources (soil, water, forests, fish, wildlife) in ecosystems and the values, attitudes, and uses associated with these resources. Since inception of field activities in spring 2001, ECASE personnel have conducted door-to-door contacts with over 300 landowners as well as numerous natural-resource professionals at the county level. More recently, a related project entitled Sustaining Private Forests (SPF) has focused attention on two of the watersheds contained within the upper Wabash River basin. SPF involves a consortium of three universities (University of Missouri, University of Tennessee, and Purdue University) in the central hardwood region of the United States. The project focuses on watersheds in each state, with the goals of (1) informing nonindustrial private forest landowners about the environmental and economic consequences of alternative land-management decisions and (2) encouraging the initiation of sustainable land-management practices that meet their needs. Engagement activities by SPF personnel began in the upper Wabash in 2002 and have involved face-to-face interviews with county extension agents, Soil and Water Conservation District personnel, employees of the Natural Resource Conservation Service, and community leaders. Additionally, over 75 in-depth interviews have been conducted with private landowners to assess the potential for collaborative planning and policy initiatives. ECASE and SPF share a stakeholder advisory council consisting of private landowners, government officials, and personnel from nongovernmental organizations with interests in agriculture, forestry, and conservation.

## INFRASTRUCTURE FOR DELIVERY OF INFORMATION

The principal mechanism for delivering decision-tool products to end users in the upper Wabash River basin is Planning with POWER (Protecting Our Water and Environmental Resources). POWER includes a significant educational component and provides assistance with technical issues and advice regarding best management practices. The Planning with POWER project receives guidance from a 15-member advisory committee. POWER coordinates the transfer of technical information derived from model-based research to decision makers (Figure 1-6).

A rather unique organizational advantage for the facilitation of planning in Indiana is the Indiana Land Use Team (ILUT). ILUT is composed of Purdue extension specialists and Purdue Cooperative Extension Service county educators specializing in land-use issues. In addition to dealing with public policy issues related to land use, the team supports county educators

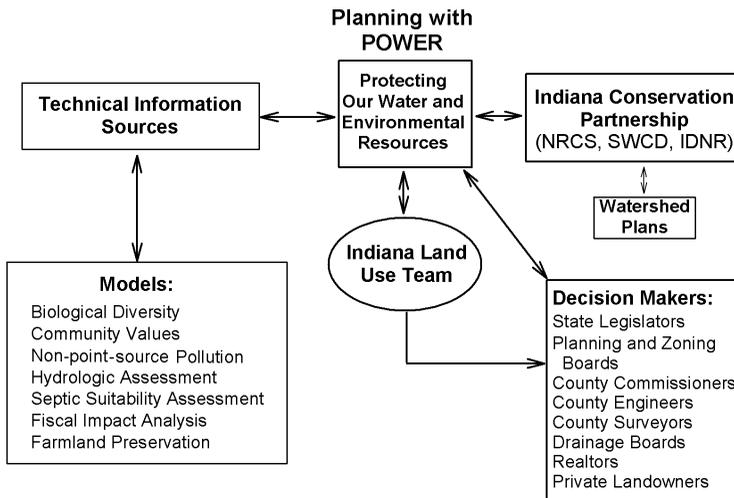


Figure 1-6. Flow diagram illustrating the infrastructure in Indiana via which modeling results and other technical information can be disseminated to decision makers involved in the land-use-planning process. Acronyms refer to Natural Resources Conservation Service (NRCS), Soil and Water Conservation District (SWCD), and Indiana Department of Natural Resources (IDNR).

serving on plan commissions and boards of zoning appeals. By state statute, county educators serve on 52 of the 78 Indiana county plan commissions (14 counties currently have no plan commission; *see* B. Miller *et al.*—Chapter 13). Thus, ILUT serves as a conduit for training and information exchange. Both POWER and ILUT are supported by the Indiana Land Resources Council, a group formed by the governor to address emerging land-use issues.

## OBSTACLES AND OPPORTUNITIES IN LAND-USE PLANNING

Although the upper Wabash River basin is an extreme example of private ownership, many human-dominated landscapes contain a high proportion of privately owned property. Private ownership by necessity increases the complexity associated with grass-roots planning efforts that are dependent upon consensus. In areas where beliefs about individual property rights are strongly held, the development of land-use planning regulations is likely to be more contentious than in areas where such rights are not as essential to property owners. When local planning boards routinely grant variances to existing zoning regulations, they effectively eviscerate comprehensive planning documents designed to encourage “smart growth” (Honachefsky 2000;

Kelly and Becker 2000). Such problems typically are encountered relatively early in the growth process for an area, before environmental resources are regarded as scarce (Rudel 1984; B. Miller *et al.*—Chapter 13).

Considerable geographic variation exists regarding the importance placed on ecological resources by local decision makers. As discussed later in this volume by B. Miller *et al.* (Chapter 13), some of this variation likely is due to temporal differences in stages of physical and cultural development of landscapes and their human inhabitants, and these differences may provide a basis for inferring future changes in biological diversity as a consequence of changes in human attitudes, demography, and policy. We believe that effective use of multi-criteria decision tools, i.e., production of accessible decision tools that are delivered to interested, informed groups of stakeholders, has the potential to accelerate the rate of cultural change regarding the importance and feasibility of natural-resource-based planning.

## ACKNOWLEDGMENTS

We thank K. P. Bell, D. Duvick, W. L. Hoover, W. B. Kurtz, K. Schaaf, and two anonymous reviewers for constructive comments on the manuscript. We also are grateful to J. Bartlett, J. Duchamp, and D. Mageean for stimulating discussion that strengthened the final product. S. Katz provided the artwork for Figures 1-1 and 1-4. B. Chivoiu assembled the data layers used for Figure 1-5 and provided the GIS estimate of privately owned land in the upper Wabash River basin. B. K. Miller was instrumental in providing insight regarding the contextual framework for delivery of modeling outputs to end users. Financial support was provided by National Science Foundation grant SES-0119908, United States Department of Agriculture Initiative for Future Agriculture and Food Systems award 2000-04649, and the John S. Wright Fund, Purdue University.

