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ECOLOGICAL SUPPORT FOR RURAL LAND-USE PLANNING

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Abstract. How can ecologists be more effective in supporting ecologically informed rural land-use planning and policy? Improved decision making about rural lands requires careful consideration of how ecological information and analyses can inform specific planning and policy needs. We provide a brief overview of rural land-use planning, including recently developed approaches to conservation. Effective participation in land-use planning requires ecologists to understand trade-offs—for example, the need to balance a land owner's desire for a fair and predictable process with the ''learn as you go'' approach of adaptive management—and the importance of integrating local knowledge with landscape-level information.

Four primary challenges require attention from ecologists to improve rural land-use planning. First is the mismatch between the spatial and temporal scales in which ecological processes occur and the scales and tempos of land-use planning. Second, ecologists must engage in interdisciplinary research to critically evaluate and determine how, if, and when ecological information influences rural land-use outcomes. Third, a comprehensive land-use framework is needed to better place ecological studies within a broader landscape context. Finally, ecologists have a key role in developing environmental indicators that directly inform local, rural land-use planning efforts.

Key words: environmental indicators; exurban development; rural land-use planning.

Introduction

Biotic resources throughout North American are threatened by rapid development of landscapes by people, particularly development of private land in rural areas (Theobald and Hobbs 1998, Dale et al. 2000, Hansen et al. 2002, Travis et al. 2002). In the United States, four trajectories of land-use change dominate dynamics in rural landscapes. The first is urbanization. Commercial, industrial, and residential development resulting from regional population and economic growth are extending relentlessly from existing urban centers. Urbanization includes the expansion of suburbs, increased road density, and upgrading of roads and other related infrastructure. The second trajectory is conversion of natural areas to agricultural or intensive forestry. Although the maximum extent of agricultural land peaked in the United States in the 1950s (Theobald 2001), some conversion to agricultural land use continues. In addition, abandonment of agriculture exposes cropland to forces of natural succession (Bürgii and Turner 2002, Hall et al. 2002). Finally, exurban or rural residential development, including construction of resorts, second-homes, vacation cabins, ranchettes, and farmettes, are perforating landscapes beyond the urban fringe. Exurban development is increasingly stimulated by environmental and recreational amenities (e.g., Ullman 1954, McGranahan 1999) and occurs throughout the United States, particularly on barrier islands in the southeastern United States; around lakes in Michigan, Minnesota, and Wisconsin (Christensen et al. 1996, Schnaiberg et al. 2002); or where private land borders public lands, such as in the Rocky Mountain West (Maestas et al. 2001, Theobald 2001, Hansen et al. 2002) or Southern Appalachians (Wear and Bolstad 1998).

These trajectories form the context of rural land-use decision making in the United States, yet the ecological consequences of land-use changes are rarely considered. Improving access to scientific information could help decision makers anticipate potential consequences of rural land-use change and in so doing, avoid unin-

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tended ecological effects. For example, in response to concerns over forest and farmland loss to development, the State of Oregon enacted the Land Conservation and Development Act in 1973 requiring cities and counties to prepare land-use plans to meet statewide goals (Abbott et al. 1994). Yet, only recently have spatially explicit studies examined how these plans and policies might affect biodiversity or natural ecological processes over time (e.g., Hulse et al. 2004). Given this context, ecologists presume that more information will better inform land-use decision makers regarding the potential ecological consequences of particular land-use plans or actions.

How can ecologists be more effective in supporting rural land-use planning and policy? Our goal in this paper is to offer guidelines about how ecological science can be more effectively applied to support rural land-use planning and policymaking. Rather than attempting a comprehensive review of a nascent field, we summarize typical rural land-use issues, describe a generalized land-use planning framework that forms the context for incorporating ecological information, and identify gaps in ecological research and the practical application of ecological knowledge to rural land-use planning.

Ecological questions associated with rural land-use planning

Land-use planners and policymakers face a broad range of issues, including provision of affordable housing, schools, water and sewer infrastructure, and emergency services. Ecological questions may also be raised during the planning process, and typical questions ordered roughly from fine to broad scale include:

1) How close can houses (or a road) be built near a lake or riparian area without adverse effects?
2) If we change land use at a given location, will populations of species *X* decline, and should we be concerned about that decline?
3) Where is habitat for Federal/State Threatened and Endangered listed species? Under what land use in the region is the habitat likely to be compromised?
4) Given that landowners have different goals for their lands, what opportunities exist to match landowner goals with biodiversity goals?
5) Where are high-priority areas of habitat, where are locations that would be suitable for restoration or improvement as part of mitigation?
6) What areas are most ecologically unique within our jurisdiction (e.g., county, city, state, etc.)?
7) What habitat types are rare regionally and therefore need protection?
8) Are there particular places and land cover types that are important to maintain landscape connectivity?
9) What are the long-term effects of modification of natural ecological processes (e.g., fire suppression in southwestern US ponderosa pine forests, health of riparian ecosystems due to alteration of hydrologic flow regime, increased proportion of impervious land cover)?
10) Do particular land-use changes increase the risk of loss to human settlements and natural resources as a result of natural disturbances or climate change (e.g., flooding and fire)?

Ecologists are particularly concerned over loss and fragmentation of rare species habitat and subsequent declines in populations from land-use changes (e.g., Dale et al. 2000). Less recognized, but perhaps of equal importance in rural areas, are potential conflicts caused by overabundant species. For example, in the West, exurban development often creates ‘‘private reserves’’ where deer and elk congregate safely without being exposed to hunting. Exurban development has been linked with increased prevalence of chronic wasting disease in mule deer (Farnsworth et al. 2005). As a result, spatial concentrations and increased population sizes of wildlife can exacerbate conflict between wildlife and agriculture, complicating management in rural areas experiencing significant exurban development (National Academy of Science, National Research Council 2002). A third concern, gaining resonance with the public, focuses on the consequences of modifying ecological processes such as wildfire and invasive species. Understanding is particularly problematic because it may take decades to centuries to clearly demonstrate the ill or unintended consequences of seemingly successful natural resource policies. Moreover, sometimes management actions that may be outside of the range of natural variability are required to direct a system back into a healthy ecosystem (Allen et al. 2002).

Land-use planning context

Ecologists must understand the land-use planning context in which ecological information might be used (Clark 1992: Fig. 1). A complex set of laws and policies at federal, state, and local scales regulate natural resources throughout the United States, yet consideration of ecological effects of land-use change does not fit neatly within the traditional federal/state/local government hierarchy (U.S. Government Accountability Office 2004). Although the ecological implications of land-use changes can often be most effectively evaluated at the regional scale, applying this knowledge on the ground presents challenges. In rural areas there is no counterpart to the 377 metropolitan planning organizations (MPOs) that have formed since 1994. These MPOs operate at a regional level as a requirement for spending federal highway funds in urbanized areas (at least 50 000 residents) and have primarily led the development and operation of an integrated, intermodal transportation system to facilitate the efficient,

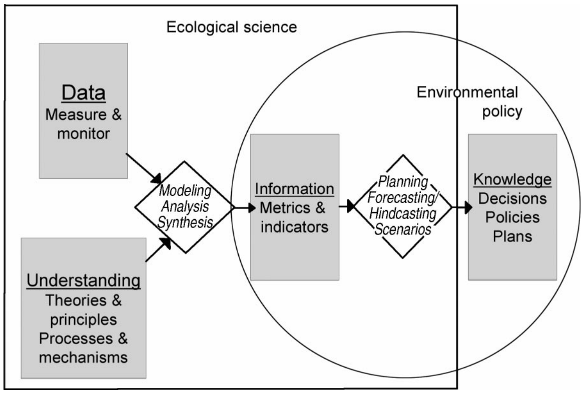

FIG. 1. A framework showing how ecological science develops information used in environmental policy. Ecologists generate data through measurement and monitoring, and use their understanding to convert data to information through process modeling, analysis, and synthesis. Ecological information applied to a study area comes in a variety of forms, often as general landscape metrics and metrics that have been found to be useful by decision makers for a particular purpose—an indicator. Ecologists also participate in the policy realm by developing forecasts from present to future conditions based on policy-relevant assumptions (and hindcasts that simulate past to present). This information is then used by stakeholders, decision makers, and managers to develop policies and plans.

economic movement of people and goods. However, the MPOs do not explicitly address healthy ecosystems in rural areas.

Planners and policymakers often lack high quality, regional-scale information about existing ecological conditions or the potential ecological implications of land-use changes. ''In recent years, a general consensus has developed on the need to judge the success of the nation's environmental policies against environmental quality outcomes. . . The adoption of such a performance-based environmental policy, however, has been hampered by the lack of reliable scientific information on environmental conditions and trends'' (U.S. Government Accountability Office 2004:1–2). For example, data were insufficient to support periodic national-level reporting for nearly half (44%) of the 103 indicators developed by the 2002 Hienz Center's State of the Nation's Ecosystems (Heinz Center 2002).

Land-use planning can involve diverse assemblages of public and private landowners, managers, and stakeholders, who must be identified, involved, and empowered if land-use planning processes are to be effective (Wondelleck and Yaffee 2000, Theobald and Hobbs 2002*a*). Given a potentially large number of stakeholders possessing different views of land use, regional planning necessarily must incorporate diverse land-use goals. This problem is exacerbated as the planning region is enlarged. As a result, ecoregional planning efforts have emerged in the United States and worldwide by nongovernmental organizations such as The Nature Conservancy and World Wildlife Fund (Groves et al. 2002). Well-focused issues in relatively well-defined geographic areas have a better chance of being addressed in planning and policymaking processes. Yet an institutional gap in planning at the regional level remains—no institution is assigned to conduct ecoregional or cross-ownership planning (Spies et al. 2002).

Despite a longstanding tradition that extends authority for land-use control to local governments (Porter 1997), decisions about land use, both public and private, are often constrained by a potpourri of policies and regulations created by a variety of federal, state, regional, county, and municipal jurisdictions. Land-use planning becomes particularly challenging in situations where intermingled public/private land ownership patterns are included because of the number of agencies, laws, and disparate interest groups involved, but also because relevant planning processes often are uncoordinated. Also, regional social and cultural differences can greatly impact planning outcomes. Different traditions and values span the spectrum from extreme property rights to common property traditions. These differences vary throughout the United States, resulting in a patchwork of federal and state laws, regulations, and policies that influence landscape patterns.

Although all levels of government may possess authority to restrict land use on private lands, ultimately land-use laws and regulations most often are applied at local levels. Each state determines through enabling legislation the extent of planning authority in counties and municipalities. The typical land-use planning structure of local governments involves two distinct processes, both of which can benefit from ecological information (Duerkson et al. 1996). First is the master planning process, which provides a vision for the types of preferred development and directs future land-use changes toward that vision using zoning and other land-use ordinances. Second, the process of development review evaluates individual projects for conformity to existing land-use regulations. Local development plans commonly are reviewed by other branches of government that have greater expertise in evaluating the ecological implications of development projects. However, this ad hoc input is usually advisory to local governments unless public monies are involved invoking federal oversight (e.g., the National Environmental Policy Act, the Endangered Species Act, etc.).

The mismatch of spatial and temporal scale (Fig. 2) underlies perhaps the toughest conundrum ecologists face when informing local land-use decision making: should the future land use of a single property be restricted because of the cumulative effects of past land-use changes on neighboring lands? The aggregate effect of land-use change is the result of many, relatively small individual decisions that are diffuse in space and time, made by a diverse array of planners and policymakers—an ecological form of ''the tyranny of small

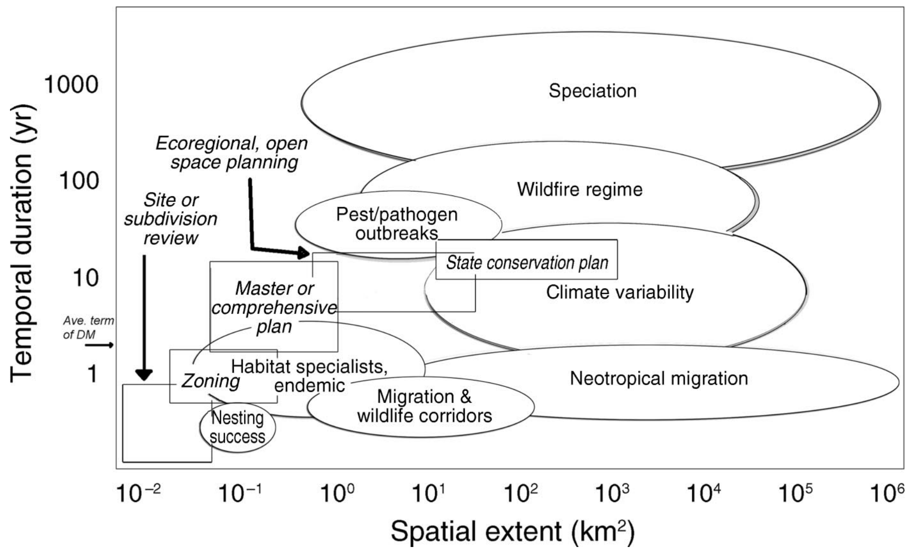

FIG. 2. There is a general mismatch between spatial extent and tempo of ecological processes, shown by ellipses, and local land-use planning activities, shown by rectangles. In particular, note that many ecological processes (such as wildfire regime, migration, disease epidemics, etc.) occur at longer and broader scales. Note that the average term of a local decision maker is approximately two years. The figure is based on Delcourt et al. (1983).

decisions'' (Kahn 1966, Odum 1982). It is often difficult to demonstrate that an individual land-use change (~100 ha) may have significant impacts on the long-term viability of a declining species or that would alter broad-scale ecological processes (~10 000 000 ha).

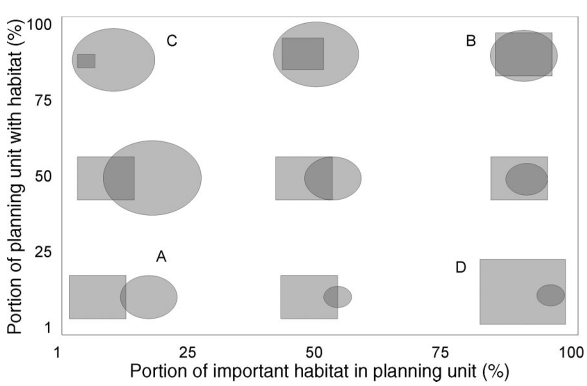

FIG. 3. The relationship of the spatial intersection between the planning unit (e.g., a county, represented by rectangles) and the extent of the important habitat for a given species (represented by ellipses) is critical. In situations where there is little overlap (A), it is difficult to show that land-use actions within the planning unit will likely have an effect (though tyranny of small decisions). As the intersection becomes a larger proportion of both the planning unit and habitat (B), there is a clearer and more direct linkage between land-use actions and the fate of habitat. In the situation where the proportion of the unit is large but is only a small part of the habitat (C), land-use actions will be important but not sufficient—coordination with adjacent and nearby jurisdictions will be required. Conversely, as the habitat becomes fully contained but remains a small proportion within the planning unit, it is easier to carefully plan on setting aside habitat to protect a species.

Yet, the cumulative effects of many land-use changes exert demonstrable impacts. For example, consider a hypothetical valley that contains 100 individual properties, each containing critical habitat. It is difficult to demonstrate that the loss of habitat on a single property is significant when a parcel is a small (e.g., 1%) portion of the total habitat, however, it is more likely that the cumulative changes of 50% or 75% of parcels is significant. Ideally ecological science would differentiate the effects of alternative approaches and identify where and when an individual land-use change will cause demonstrable impacts. Currently, ecological science can only identify relative risks of different courses of action or provide expert opinion from scientists based on first principles.

The precautionary principle (Cooney 2004) is occasionally invoked as well, but is unlikely to withstand immediate demands for economic development. An additional concern often expressed as the aphorism ''death by a thousand cuts'' is raised when only a small proportion of critical habitat is located within any single jurisdictional boundaries (Fig. 3). Differences in the frequency of decisions between agencies that plan land use on publicly vs. privately owned land (e.g., decadal cycle of the National Forests vs. monthly to yearly in counties and municipalities) also can make coordination among multiple planning jurisdictions difficult (G. Wallace, *personal communication*).

Currently, much rural land-use planning is regulatory based (e.g., zoning) and restricts certain land-use activities. However, a number of other incentive-based land-use tools, such as conservation easements, purchasable or transferable development rights, fee-simple purchase, and cluster developments, are receiving renewed attention because they encourage desirable land uses by offering positive incentives to landowners (Theobald and Hobbs 2002*b*, Hilty and Merenlender 2003). For example, in 2001, over 2.6 million hectares have been protected by local and regional land trusts (Land Trust Alliance 2001). The information needs for strategic protection by land trusts may be different from those of the more standard policy tools, for example development of a certification system for ''green development'' that awards points based on meeting ecological criteria. Ecologists should be involved in evaluating the efficacy of a full range of policy options. Doing so will require collaboration with economists, political scientists, landscape architects, planners, and other social scientists.

Data integration and communication

What are the most effective ways to integrate ecological information into rural land-use planning processes? One of the most important ways is through collaboration among stakeholders from federal, state, and local government, and private organizations, groups, and individuals (Theobald and Hobbs 2002*a*, Cohn and Lerner 2003). As with other forms of collaboration (Likens 1998), significant investment in the process itself is needed to establish credibility and trust among project members. Collaborative planning efforts could be facilitated by expanding traditional roles of regional planning agencies, watershed councils, and extension agents beyond their important educational and integrative roles to empower these groups, perhaps by extending some limited decision making authority to them. Also, it is important to support actively engaged field ecologists with consistent, timely, and pertinent information that complements their local, ''in-the-field'' experience and knowledge.

A common challenge in efforts to inform land-use planning is to integrate data from a variety of agencies and administrative units into a cohesive, consistent database. Although there are some notable recent efforts to better standardize geographical data, such as the National Spatial Data Infrastructure and the U.S. Geological Survey's Gap Analysis Program, it remains a formidable task to develop and make these data accessible and usable. Further, regional databases are suitable for identifying critical habitat and biodiversity hotspots within a large area (i.e., >1000 ha), but they usually are unsuitable to identify whether a particular landowner's property (i.e., 10 ha) has critical habitat or not. The credibility of projects can be jeopardized without careful consideration of whether the scale of data is sufficient to meet certain stakeholders' expectations.

The ability to customize regional models using ''local knowledge'' is needed as well. Although ecologists usually come to a land-use decision process as invited experts, the knowledge of local stakeholders must also play a role that is valued by ecologists. Ranchers, farmers, and public land agency personnel often have tremendous knowledge of the flora, fauna, and traditional use of the natural resources of local areas. This knowledge is often richer than the information provided in typical comprehensive land cover maps. Integrating this knowledge into spatial data and simulation models is critical, both to improve the quality of information produced and to honor the contribution of all stakeholders. Ecological support for rural land-use decisions should be conceived as collaborations that ensure mutual sharing and learning among all parties, rather than the simple transfer of knowledge or technology from experts to decision makers (i.e., yet another ''outreach'' effort). Ecological support should come from an exchange rather than an export of information.

A number of technological advances provide unparalleled opportunities for using ecological information to inform rural land-use planning. Geospatial technologies such as geographic information systems (GIS) allow spatial data to be collected, integrated, analyzed, and visualized in relation to other environmental and land-use factors. Simulations based on spatially explicit data can be used to examine the consequences of various assumptions on the landscape. The Internet can provide ready access of ecological information to rural land-use decision makers. For example, the Colorado Natural Diversity Information Source (*available online*)[8] was developed to support planning by local communities by providing readily accessible information on the consequences of development for wildlife. It allows planners, decisions makers, and citizens to foresee how cumulative changes in land use over time are likely to affect the extent and distribution of habitat for wildlife (Theobald et al. 2000). Additional opportunities exist through public-participatory research to formalize modes of public interaction with spatial data. For example, visual modeling languages help to explain the logic of models. Interactive ''white-board'' interfaces to computers offer the potential stakeholders to examine, in real-time, the effect of various assumptions that will more fully engage participants (Nyerges et al. 2002).

Models are particularly useful tools to integrate ecological information and communicate assumptions, potential uncertainties, and the complexity of feedbacks to decision makers (Dale 2003). Throughout the United States, efforts to map alternative future land-use patterns and examine the implications of those changes have been particularly useful and an increasingly common way to integrate ecological information with other socio-economic concerns in long-term, comprehensive planning processes (e.g., White et al. 1997, Wear et al. 1998, Theobald and Hobbs 2002*b*, Hulse et al. 2004).

[8] ⟨www.ndis.nrel.colostate.edu⟩

Most efforts to date have yet to fully incorporate ecological mechanisms to these assessments, however.

Research and application gaps

A number of research and application gaps need to be bridged to better inform rural land-use planning. Traditionally, ecologists are inclined to vigorously pursue filling gaps in ecological knowledge. For instance, a principle goal is to understand functional properties of organisms and their relationship to spatial heterogeneity of resources to predict population viability (often related to Endangered Species Act requirements). Synthesis of spatial databases into simulation models is important as well. The foundation of information supporting rural land-use decisions is a high-quality spatial database. To improve these data, we need better mapping of fine-scale landscape features (e.g., tree snags, nests, riparian areas, etc.). Promising new mapping approaches integrate satellite imagery, GIS, and ground plots to estimate fine-scale habitat elements (e.g., Ohmann and Gregory 2002). Although techniques to map land cover using either aerial photos or satellite imagery are improving, mapping land use remains challenging, particularly when mapping rural residential development, where a land-use change often causes only a small footprint which is often invisible (Theobald 2001). Land use can be inferred from landowner parcel data that are becoming available through local governments, yet even current basic datasets on land ownership (e.g., USFS, BLM, private, easements, etc.) are generally not available. Moreover, detailed information about human activities on public lands (especially recreation) generally is unavailable, and so identifying potential conflicts between biological resources and human activities are difficult.

Progress has been made in developing empirical models and simulation approaches to examine land-use change using broad-scale spatial databases (e.g., Landis 1995, Theobald and Hobbs 1998, Brown et al. 2000, Maxwell et al. 2000, Theobald 2001, Aspinall 2002, Kline et al. 2003); and in examining the ecological effects of these changes (White et al. 1997, Hansen et al. 2002, Theobald 2003). Consideration of the variety of model approaches is needed to understand their utility in different decision making contexts. Most spatial landscape-level models focus on ecological change in forests and ignore climate change, catastrophic events, and vegetation dynamics in non-forested land-use areas. Thus, extant models may apply poorly to many areas of the nation undergoing rapid changes in land use and land cover. Routine integration of socio-economic factors, which largely are responsible for motivating land-use changes, is usually absent from landscape models developed by ecologists. This absence limits the realism of ecological evaluations of alternative policy actions, such as protection of biodiversity (Polasky et al. 2001, Musacchio and Grant 2002). Also, landscape-level models need to better account for the combined influences of uncertainty and error associated with individual modeling components, in resulting landscape simulations and predictions.

A final gap, one in which ecologists typically have little experience, is in the effective application of ecological knowledge. That is, it is not enough to simply produce useful ecological information in a timely manner, rather it must be carefully incorporated into rural land-use planning through effective communication in the proper decision making processes. This step often requires staff and institutional support to create and run models, help users interpret output, and describe uncertainty and appropriate uses of models to decision makers. Because of the critical need to develop consistent, comprehensive, and credible ecological databases and information delivery tools, a new and important opportunity exists to expand the role of ecologists and existing institutions, or to create new natural resource science institutes that are unaffiliated with advocacy groups.

Ecologists have a timely and important role to assist in the development of environmental indicators that provide decision makers and the public with information to set priorities and assess the efficacies of land-use policies. To ensure the success of indicators, a sound process must be followed to develop indicators, sufficient data must be collected to report status and trends, and changes in indicators must be linked to specific management actions and land-use policies (U.S. Government Accountability Office 2004). A logical next step is to build on the progress of national-level efforts (e.g., Heinz Report) to develop targeted indicators for local planning processes. In particular, there is a need to develop a set of standardized indicators for rural landscapes that have received scientific review, are based on detailed spatial data that resolves fine-scale features (e.g., houses, small wetlands and riparian zones, etc.), and that respond directly to changes in land use (J. Bennett, *personal communication*).

Ecologists who develop integrated models face difficult problems when incorporating data from multiple sources that are characterized by varying degrees of accuracy. To maximize confidence in model output, assumptions and data manipulation for models must be transparent, and where models are used to predict, output should be called forecasting (Clark et al. 2001), projections (Dale and Van Winkle 1998), or scenarios (Schoonenboom 1995). Where possible, models should include the measured variation in data or some assumption about variation (particularly associated with local knowledge) and process outputs as probabilities rather than deterministic responses. Models must clearly portray uncertainty in forecasted outcomes and portray results as best estimates of experts rather than as calculated facts. Evaluation of the effects of alternative land-use scenarios is a useful way to do this (e.g., Steinitz 1996, White et al. 1997, Theobald and Hobbs 2002*b*, Hulse et al. 2004).

Future studies should identify successful situations to determine the ways in which ecological information was helpful and to critically examine failures as well. Colleagues from other disciplines, especially political science and sociologists, could assist ecologists in the use and application of ecological information and tools in the rural land-use process. For example, interdisciplinary teams should critically examine whether and when ecological information changed a land-use decision, how it was used by decision makers during deliberation, and what information was missing or how information that was provided could be improved.

Conclusions

We believe that ecologists can be more effective in supporting wise decisions on rural land use. To that end, we have offered a brief review of recent ecological work, sketched the typical rural land-use planning framework, and identified some emerging useful approaches to incorporating ecological knowledge in established decision making processes. We are encouraged by an increasing level of awareness and enthusiasm from ecologists for the critical need to improve ecological support for rural land-use planning (e.g., Perlman and Milder 2005). Unfortunately, we have been challenged to find useful examples of truly outstanding or successful projects that have informed rural land-use planning. We do not mean to imply, however, that ecologists are having no influence on rural land-use planning. Rather, we conclude there is a paucity of organized and systematic efforts to evaluate and learn from applied projects.

We believe that four fundamental challenges remain that require additional attention from ecologists. First, there is a mismatch in spatial and temporal scales where ecologists have the greatest understanding and those where land-use decisions occur (Fig. 2). In addition, critical and systematic evaluations of how, if, and when ecological information has influenced land-use outcomes are needed. Ideally, these should be conducted by social scientists to better understand how ecological information is used, how it can be improved, and what different information is needed.

For instance, although NDIS is arguably successful in informing land-use planning with readily available biological information, it remains difficult to provide objective measures of its success. How many land-use decisions have been influenced by NDIS? How many times have NDIS maps been considered during land-use hearings? How many county supervisors, planning and zoning commissioners, or interested citizens have visited the NDIS website? How many students have used NDIS as a source of information for their research projects? Regrettably, we do not have good answers to these questions. Ecologists excel at producing data and insight, but improving the relevancy and practical application of ecological science requires that ecologists critically evaluate its use and efficacy.

Moreover, standard land-use frameworks used to classify the type of land use (i.e., urban, suburban, agricultural) or the level of stewardship and protection require significant refinement. Negative ecological effects are typically inferred from classes of land use such as high-density residential, commercial, or dryland agriculture, but more detailed examination and analysis are needed to identify specific, measurable factors of these effects. For instance, are impermeable surfaces, maintenance of exotic species (lawn), modification of vegetation structure (trimming, thinning), etc. the main land cover modifications of high-density residential land use that cause impacts? What activities associated with high-density residential have impacts (e.g., Lepczyk et al. 2004)? Are the major activities that impact ecological systems free-roaming cats and dogs, increased automobile traffic and associated noise, presence of humans? Coarse classes or levels of stewardship (e.g., U.S. Geological Survey's Gap Analysis Project Status I-IV and IUCN's I-VII; Davey 1998) also need to be refined to explicitly examine allowed activities (e.g., active vs. passive recreation) and possible modification of disturbances such as fire suppression or unintended introduction of disturbances from activities such as mechanical thinning.

Finally, a critical component of adaptive management is missing in land-use planning—monitoring and evaluation. For example, a monthly or yearly summary of environmental performance should be assessed using ecological indicators that directly measure land-use decisions. These indicators could include the decrease of critical habitat (or increase through restoration), increase or decline of protected lands, change in air quality due to vehicle miles traveled, etc. Yet, effective participation in land-use planning requires ecologists to understand trade-offs, for example the need to balance a land owner's desire for a fair and predictable process with the ''learn as you go'' approach of adaptive management. Perhaps most importantly, ecologists must challenge the assumption that simply providing better ecological information and knowledge leads to better land-use planning. Broberg (2003) emphasized the direct roles that ecologists may play (rather than in generating information per se) in the planning process, from less to more direct: generate recommendations while participating in citizen review panels, testify at public hearings, educate staff and planning boards, and become planning board members. Ecologists have a significant and important role in generating and sharing scientific information to decision makers to help anticipate possible unintended ecological effects of rural land-use change.

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