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Incorporating biological information in local land-use decision making: designing a system for conservation planning

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Abstract

Human settlement is a formidable agent of change affecting fundamental ecological processes. Decisions governing these land-use changes occur almost exclusively at the local level and, as a result, they are made at many different locations and times. Consequently, it is difficult for ecologists to provide needed scientific support for these choices. We built an information system designed to support conservation decisions at local scales by offering data over the Internet. We collaborated with local stakeholders (e.g., developers, planners, politicians, land owners, environmental activists) to design the system. This collaboration produced several generalizations about effective design of information systems to support conservation. The most important of these is the idea that ecological data and analysis must be understood by those who will be affected by the decisions. Also, planning for conservation is a process that uses scientific data, but that ultimately depends on the expression of human values. A major challenge landscape ecologists face is to extend general landscape principles to provide specific scientific information needed for local land-use planning.

Introduction

Throughout the world, human land-use is a formidable agent of change, shaping the distribution of land cover and affecting fundamental ecological processes – hydrological/climatological regimes, biogeochemical cycling, and the persistence and extinction of species (Vitousek et al. 1997). Although human activities like silviculture and agriculture result in land transformations over large areas of the earth's surface, few alterations of the land are as profound as human settlement (Douglas 1994). During 1982–1992, urban and built-up areas replaced more than 56,655 km^2 of pasture, cropland, range, and forest on private lands in the continental US (USDA 1998). These same private lands subject to development contain disproportionately high levels of biodiversity (Bean and Wilcove 1997) and habitat for rare species. For example, fewer than 10% of endangered species occur exclusively on public land (GAO 1994).

Conversion of private agricultural land to low-density residential development and associated infrastructure was particularly rapid in the Rocky Mountains, where the area of land developed increased by more than 21% during the 1980s and early 1990s (USDA 1998). Regional projections of population growth suggest that these increases are likely to accelerate during the next century. It follows that development of farms, ranches, and forests will markedly alter the landscapes of the western US in the coming decades, and these alterations will exert strong and lasting effects on the quality of life (Riebsame et al. 1996). This recognition has given rise to many efforts to shape the course of change in such a way that natural systems are preserved and protected in the face of rapid environmental change. Landscape ecologists can play a vital role in these efforts by supporting decisions on land use with insights into the consequences of land-use choices for the ecosystems of the region.

However, the participation of ecologists in land-use decisions is made difficult by the political context in which these decisions are made. A longstanding tradition in the US and formally manifested in culture and law, extends authority for land-use choices to the lowest possible level of government (Porter 1997). The Constitution and its interpretation by the courts grants individual landowners enormous discretion about how to use and profit from their land. Although government can constrain a landowner's options for development, these constraints are almost always applied at the local level – that is, by counties and municipalities. For example, the basis for county oversight of wildlife resource protection originates from state land use control acts. Colorado's Land Use Control Act (S.B. 1034) states the need for 'protecting lands from activities which would cause immediate or foreseeable material danger to wildlife habitat and would endanger a wildlife species.' Because these levels of governments form the base of the political hierarchy in the U.S., it follows that decisions on land use are many in number and diffuse in space and time (Figure 1). Thus, the aggregate effect of land-use change results from the accumulation of many, relatively small decisions by individual landowners and local governments, an ecological example of the tyranny of small decisions made singly (Kahn 1966).

Traditionally, ecologists have been successful in influencing public policy by affecting decisions at the top of political hierarchies – scientific input to Congress or to the heads of agencies resulting in regulations that have sweeping effects (e.g., the Endangered Species Act). However, it is clear that ecologists must use local, 'bottom-up' approaches if they are to have meaningful impact on land-use decision making.

Local land-use planning affords a great opportunity for protecting natural systems because local communities can develop land-use plans that are proactive rather than reactive, thereby providing stewardship before restoration or mitigation is necessary (Karr 1990). Such planning efforts can broaden single-species approaches to encompass biotic communities and habitats and can offer a wide range of planning tool in addition to regulatory mechanisms (e.g., incentive-based options; Duerkson et al. 1997). This opportunity to influence local land-use planning is matched, however, by a significant challenge. Local land-use planning rarely incorporates the best available data, partly because access to the data is limited, and partly because it is not clear how the data can be used in the planning process (Cort 1996). This failure results most frequently because the hard-won data are inaccessible – the participants in land-use decisions simply do not know where to get the data, or the time required to put the data in a useful form prohibits their routine use (Meredith 1996). Therefore, ecologists are challenged to bring scientific understanding of natural systems into the planning process.

Here we describe a system that supports local land-use decision making by providing credible and pertinent ecological data and analyses to planners, decision makers, and citizens. Our approach is similar to gap analysis (Scott et al. 1993) in that we use maps of vegetation and species-affinity data as a basis for identifying important habitats for long-term planning efforts. However, whereas gap analysis is typically used for regional-scale assessment and design of reserves (Flather et al. 1997; Scott et al. 1993), our approach is different in that we focus specifically on the local land-use decision-making process. This focus required that we use data appropriate to support decisions on areas as small as 50 ha, provide analyses useful for development review in addition to longer-term, master planning efforts, and map patterns of private land development, especially conversion of agricultural to residential land use. The best available ecological data were incorporated into a pilot planning system designed and implemented in Larimer and Summit Counties, Colorado. We conclude with some thoughts on how ecologists can more effectively influence conservation planning at the local level.

Methods

We initiated a project called System for Conservation Planning (SCoP) to support planning by local communities in Colorado by providing them with information on the consequences of development for wildlife (Hobbs et al. 1994). The objective of the project was to produce an information system that assembled data and analyses on wildlife populations and habitats and that made those data readily accessible over the World Wide Web. This objective was motivated by

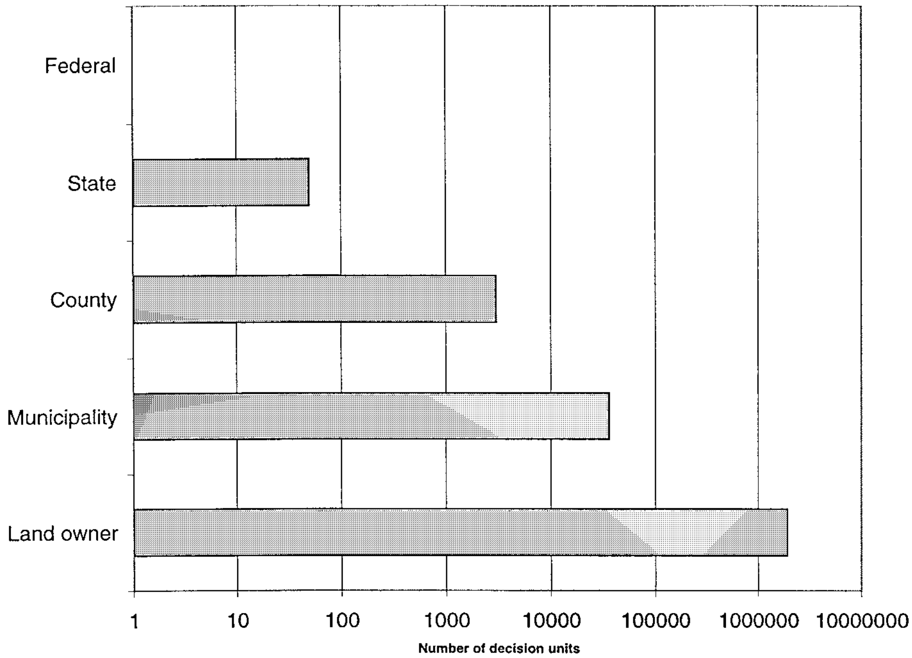

Figure 1. Land use decision making hierarchy in the US. This shows the number of jurisdictions (decision making units) with legal authority for making local land use decision making. Land owner is the number of large acreage agricultural land owners, a reasonable approximation of the potential number of land use decisions in the US, which assumes that agricultural conversion is the primary form of land use change in the US.

the idea that easy access to data could help inform a variety of participants in land-use planning at the local level. Such participants included decision makers (e.g., county commissioners) and their staffs (e.g., planners) as well as the citizens who wished to influence the outcome of decision making processes (e.g., environmental advocates, landowners, developers).

We recognized a timely opportunity to meet these goals because many local governments have recently compiled spatial databases on private land use and development that complement emerging natural resource data assembled by state and federal agencies on vegetation, hydrology, and distributions of many wildlife species. We believed that these data could be brought to bear on local decisions by developing methods for analysis and display that were accessible by all participants.

Although there was a clear opportunity to use newly available spatial data in the planning process, it was also clear that supporting decisions on conservation with scientific data would depend on the extent to which a scientific viewpoint could be integrated with the diverse views of the users of the data. In particular, we believed that developing a useful system would require the cooperation of all users who have a stake in the decisions. That is, understanding the needs of our "clients" was critical to system design and implementation. Achieving such understanding required input and direction from people from a broad range of backgrounds – scientific and technical expertise alone would not be sufficient.

We used a process known as collaborative design to identify goals for the information system and to develop preliminary sketches of how the system would work. Collaborative design is based on the idea that the best products result from interactions between people who know how to make products and people who will ultimately use them. Thus, we assembled a 'design team' consisting of a group of potential users including a county commissioner, a planner, a developer, a land owner, a wildlife manager, and some environmental advocates. Technical expertise was contributed by ecologists, geographers, a land-use attorney, and computer programmers.

We held a number of meetings with the collaborative design team. Each session followed an iterative cycle of listening to user needs, getting feedback, and designing as a group, resulting in an incremental system development. The design that emerged from these sessions focused on addressing three important parts of the local land-use planning process: master planning, site review, and assessment of cumulative impacts.

Linking information to decisions

In order for biological information to be influential in local planning, it must be carefully and strategically linked to the decision-making framework of the planning process (Duerkson et al. 1997). Two types of planning typically occur at the county level: master planning and site review. Master or comprehensive planning provides a countywide 'vision' and establishes the goals and policies for long-term land-use decisions. These master plans are advisory – not regulatory – and the implementation of the policies depends largely on the political will of the local elected officials and the stability of their constituency. Master plans span the duration of individual officials' tenures, and hence are important in maintaining a consistent policy direction over time.

The site review process is triggered as individual developments and zoning changes are proposed. Criteria for decision making during site review include, in addition to stewardship of wildlife resources: compliance with zoning, adequate water supply and sewage disposal, compatibility with soils, topography, and hazards, adequate access to transportation systems, and maintenance of affordable housing. A major challenge ecologists face is to inject scientific information and analyses into the planning process where varied objectives, frequently competing, are brought together to form an integrated whole (Rockwood 1995).

System implementation

Recently, landscape ecologists and conservation biologists have distilled their experiences from a number of conservation efforts and have developed a number of conservation principles that can be used as a basis for planning (Murphy and Noon 1992; Noss et al. 1997; Peck 1998). These include: (1) species that are well distributed across their historical range are less prone to extinction, (2) large patches that support large populations support them for longer periods of time, (3) habitat patches that are continuous (less-fragmented) support long-term viability, (4) patches that are sufficiently close together allow dispersal and thus support long-term viability; (5) patches that are connected by corridors provide better dispersal, (6) patches of habitat that have minimal or no human influence (e.g., roads) are better, and (7) populations that naturally fluctuate widely are more vulnerable than stable populations.

However, we faced a formidable challenge when identifying conservation principles at a landscape scale that could be used to provide a scientific rationale and support the *specific* types of information and actions identified by our design team. Part of this difficulty was caused by a lack of detail in the scientific principle, in particular how to measure and apply it. Pragmatic constraints of data availability also caused difficulty. We started with biological principles for habitat protection at the landscape scales (Duerkson et al. 1997) and matched the specific information needed to support a particular decision with credible scientific data (Table 1, details of the individual maps and lists are found in the text below).

Results

Site review: concerns if developed

The collaborative design team felt an important application was for a user to be able to identify a site on a map and obtain a quick overview of the concerns about impacts of development on wildlife and natural communities that would likely be raised in a review of proposed development at that site.

Two users clearly expressed this need. The developer asked for this function to learn about potential conflicts caused by impacts of development on wildlife before he invested a great deal in a development proposal. The environmental advocate wanted to be able to develop a set of informed 'speaking points' to raise about impacts on wildlife that might result from a proposed development. Both team members with often dissimilar viewpoints asked for essentially the same information, presented in the same format. This 'coarse-screening' approach assisted all stakeholders in the planning process by providing more certainty to the planning process, especially by allowing potential problems to be identified up front, before much time, energy, and money were invested. Such a screening, if major concerns were identified, would trigger further field-based investigation, data collection, and possibly a plan outlining site-specific activities to conserve habitat or mitigate potential impacts from development.

To address these needs, we used two sources of biological data, a vegetation map classified from a Landsat TM satellite image, and maps of the known

Table 1. Biological principles and their scientific rationale for wildlife conservation (adapted from Duerkson et al. 1997).

Landscape principle	Information needed to support design team	Data issues
1. Maintain large intact patches	Patch quality map	Functional definition of a patch needed
2. Establish priorities for species protection and protect habitat for rare and sensitive species	Lists of: • threatened and endangered (T&E) species • economically-important species • declining species Maps of: • known distributions of (T&E) species • Natural Heritage conservation sites	Based on multiple sources of data; predicted suitable habitat, known distributions, site occurrences; user can modify lists based on local knowledge of vegetation
3. Protect rare landscape elements	Maps of: • rare vegetation types • Natural Heritage conservation sites	Very difficult to resolve fine-scale habitat features (e.g., snags, cliffs, riparian zones)
4. Maintain connections	Maps of: • Migration corridors for big game • Corridor map based on impedance	Limited knowledge of what constitutes a corridor Limited field data on corridors Difficulty in interpreting impedance map
5. Maintain ecological processes	Maps of: • Natural Heritage conservation areas (boundaries are drawn to include biological processes needed)	Difficulty of predicting and mapping frequency, extent, and timing of processes
6. Contribute to regional persistence by local conservation	Maps of: • Statewide vegetation (e.g., GAP)	Difficulty of comparing habitat information derived from different sources and scales
7. Balance opportunity for recreation with wildlife needs	Maps of: • Housing and road development (historical and projected)	Key is to steer development toward common habitat; lack data for recreation numbers by use and location and their impacts

distributions of wildlife species. We used the vegetation map to model potentially suitable habitat (PSH) for all of the vertebrates in each county. We modeled PSH based on affinities of vertebrate species for vegetation classes, as documented by standard references (White et al. 1997). Each cell in the vegetation map was classified as habitat if a given species used the vegetation class found at that cell and the elevation was within the species elevational range. For species that were associated with water, we also required that appropriate water bodies be sufficiently close to the map cell if the cell was to be classified as suitable habitat.

Information on PSH is critical because we are lacking known distributions for most species, especially non-game species. For example, the Colorado Division of Wildlife had known distribution maps for only 24 of 221 non-game vertebrate species thought to be in decline in Colorado. Maps depicting known distributions resulted from opportunistic rather than comprehensive data collection, so that areas outside of the known range may simply not have had any studies searching at these locations. These two types of habitat data (predicted and field-based) are not viewed as being mutually exclusive, rather they are complementary (Figure 2).

The SCoP system was designed so that users could locate sites using standard maps – elevation, roads, streams, towns, land ownership, and place names. A user could identify an area of interest (AOI) by drawing a box on these ‘locator maps’. In response, the system dynamically builds a report for the user describing several biological attributes of the area. These include the following:

- A list of threatened or endangered species that have PSH within the AOI. Clicking on a species in the list allows the user to obtain maps for that species’s habitat and distribution. The system also provides a text description of the species’s status, life history, and management practices that enhance or harm habitat for the species. Finally, the system calculates and reports the proportion of the species’s habitat in the county that would be impacted if the AOI were to be fully developed.
- A list of economically important species that have PSH or known distributions within the AOI. Clicking on a species in the list provides the same types of maps and text described above.

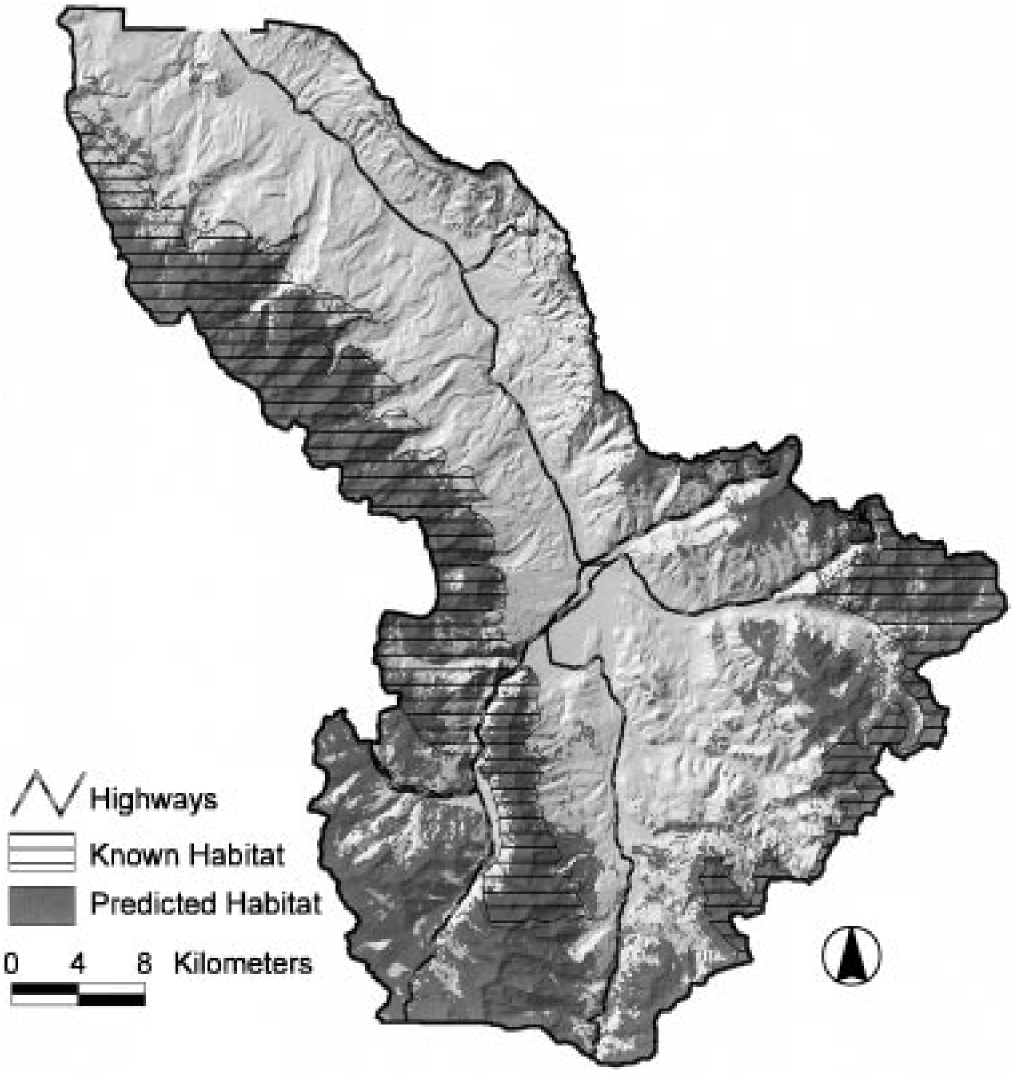

Figure 2. A comparison of modeled and known mountain goat (*Oreamnos americanus*) habitat distribution in Summit County, Colorado.

- A list of species that have known distributions or occurrences within the AOI. For example, if the AOI contains critical winter range for elk, nest sites for bald eagles, or occurrences of a species observed in a field survey, the system reports those findings to the user.
- A 'red flag' that is raised if the AOI contains any areas that have one or more important wildlife values, including rare native vegetation types (typically less than 3% of county individually), known distributions of sensitive and rare species using Colorado Division of Wildlife data on listed species and Colorado Natural Heritage Program conservation sites and element occurrences, limiting habitat for economically important species (e.g., elk severe winter range), and/or areas with particularly high species richness (areas that exceed 95% of species richness calculated using a 0.5-km radius of each map cell).
- A comparison of the expected species richness within the AOI relative to expectations for areas of similar size throughout the county. We estimate a species-area curve for the county based on PSH. We similarly estimate the number of species that have PSH within the AOI, and compare this estimate with the predictions of the species-area curve.

Thus, our 'concerns if developed' application within SCoP offered a quick screening of several biological attributes of an AOI, attributes that might trigger mitigating measures during review of development proposals. We emphasized to our users that the information reported by the system was subject to errors of omission and commission, and that it should not serve as a substitute for on-the-ground inspection of the site. Instead, the application alerts advocates and developers to issues that may require action, and informs government officials, including planners and wildlife specialists, about attributes to verify during site visits.

Comprehensive planning: habitat value

Our design team also asked for an application within the system that would support comprehensive planning. They asked for a series of maps that displayed areas that had high value as wildlife habitat, and perhaps more importantly, areas that were *not* especially valuable. The idea was that planners could use these maps to 'steer' concentrations of development away from high value areas in the same way that development is encouraged to avoid viewsheds, floodplains, and unstable soils.

To meet this need, we worked with the design team to identify habitat maps and indices that provided a rational, scientific foundation for goals in comprehensive plans. We held a series of workshops to explain these principles to the design team and to discuss with them how the principles might be used to develop maps of biologically important areas of the landscape. Based on these workshops, the team asked that the system display several maps of habitat value. We responded to their request as follows.

We addressed the need to identify areas of high-value habitat by producing three types of maps. First, we created a series of maps to identify areas of the landscape that offered habitat for unusually large numbers of native vertebrates. We created local diversity maps by summing all vertebrate species that had potentially suitable habitat (PSH) within a given map cell. This map identified areas that offer high levels of species diversity resulting from overlap of habitats of individual species. We also created a neighborhood diversity map by counting the number of species that have PSH within a 500 m radius of each map cell and assigning the count to the central cell (Figure 3). This map identified areas that offer high levels of species diversity as a result of the juxtaposition of vegetation types. Similar maps of local and neighborhood diversity were created for sensitive species, listed species, and those known to be in decline.

Second, we created a map to identify large, intact patches of habitat. The patch value map was calculated by identifying all vegetation patches with greater than 50 cells, where patches were comprised of contiguous cells using an 8-neighbor search. For each patch, we found the number of species that have PSH within the patch. For each species within an individual patch, we calculated the proportion of the total area of habitat for the species contributed by the patch. The habitat value score for the patch was the sum of these proportions taken across all species. Thus, the patch value map identified large intact patches of vegetation and weighted them by relative rarity of species' habitat. All other things being equal, large patches had higher value than small ones. However, small patches were given greater weight if they comprised a large proportion of a species's habitat.

Third, we created a corridor map to identify areas critical to the movement of large vertebrates. The map was calculated by first identifying groups of species using similar vegetation types through cluster analysis. The five largest, intact patches of habitat for each of the clusters were then delineated. We then calculated an impedance map assuming that resistance to movement was least among cells that included habitat for the cluster of species, and greatest in areas of inhospitable habitat, which also reflected road density. We then summed the impedance map across the clusters of species and normalized it to range between 0 and 1. High impedance was taken to mean low corridor value.

While it is possible to produce a 'composite' map of habitat value by algebraically combining values across cells in distinct map layers, we resisted doing this because the various methods of assessing habitat value are not commensurable: hence, there is no clear relationship on which to base an equation that could be used to combine them. Although some techniques have been developed to combine different map layers (e.g., USFWS 1983), all assign, explicitly or implicitly, a weight to the individual layers. Such assignments of weights are highly subjective, though there are a growing number of techniques to combine expert opinions into a weighting scheme (e.g., the analytical hierarchical method). Moreover, when we discussed creating a composite map with the design team, the consensus was that understanding the individual layers would always be required to make

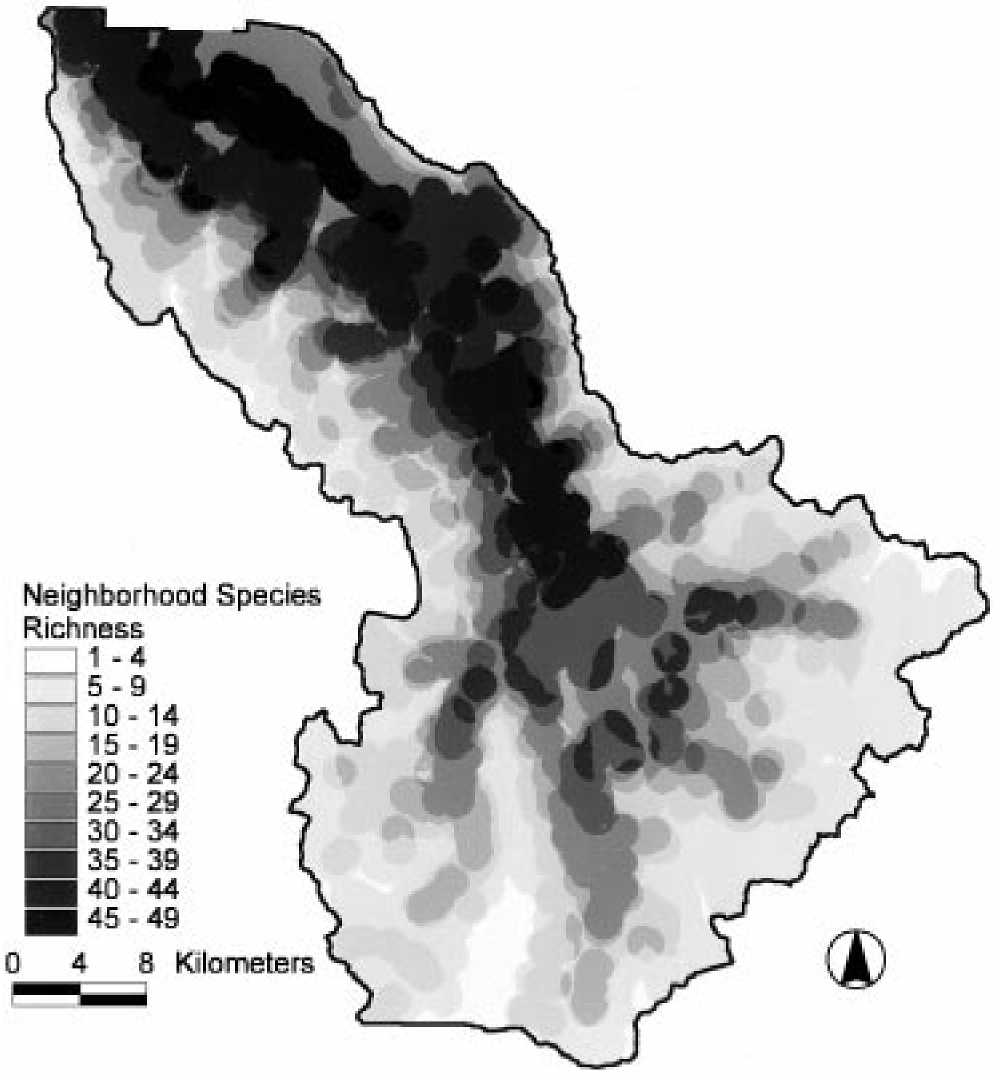

Figure 3. Neighborhood species richness in Summit County, Colorado. This map shows the number of vertebrate species that have potentially suitable habitat within a 0.5 km radius of each 30 m pixel. The total number of species modeled was 51.

a decision, and that a composite map would obscure rather than clarify the data.

Cumulative effects

Regional changes in land use result from many local decisions, often made one at a time. This is problematic because an unstated assumption in planning for human population growth is that habitat lost in one place can be compensated by habitat remaining undisturbed elsewhere. It is clear that this assumption cannot hold forever as many small, seemingly benign impacts can accumulate over time and ultimately threaten wildlife habitat and biological diversity. Increasingly, there is a need to support decisions about wildlife habitat and impacts of development in the face of rapid human growth. One simple method is to create a series of maps depicting historical growth patterns. The next step is to complement historical data with projections of future development patterns. Comparison of future scenarios that reflect alternative development patterns has been used as a method to evaluate cumulative impacts (Steinitz et al. 1996; White et al. 1997).

We provided an assessment of cumulative impacts of development on wildlife habitat by developing a spatially-explicit simulation model (Theobald and

Hobbs 1998). Development pressure was calculated by converting human population projections (from the Bureau of Census or state demographer's offices) into the number of new housing units. These new units were distributed across the landscape based on the probability of development, which was influenced by distance from existing development and modified by zoning. An analysis of historical data provided the transition rates based on existing neighborhood housing density. Areas that were closer to existing development were more likely to be developed (Theobald and Hobbs 1998). Planning actions such as changes in zoning and incentives for clustered development were simulated as well by altering the probability of development, adjusting the area of disturbance around individual buildings, and/or modifying the build-out density. The resulting housing density patterns were related to the expected disturbance of wildlife habitat by calculating the disturbance zone produced by changes in vegetation, predation rates, and wildlife avoidance of development (Theobald et al. 1997). Increasing housing density had different effects depending on existing housing density. At low existing densities (rural), the addition of even a few houses has large effects, while at moderate (suburban) and higher (urban) densities, the impact was very small.

Discussion

It is too early to assess fully the success of our efforts in protecting biotic resources. Maps from the SCoP project have been adopted as part of master planning and development regulations in two counties, and the system has been expanded to offer information to local governments statewide. The efficacy of these efforts in achieving conservation goals will be tested as the information system is used more widely and frequently.

However, our collaborative design process offers lessons that are useful today. Probably the most important of these is the idea that ecological data and analysis must be understood by those who will be affected by the decisions. In other words, citizens participating in planning processes '. . . will not support what they do not understand and cannot understand that in which they are not involved' (FEMAT 1993, II-80). For example, the scientists on our design team originally advocated development of generalized population viability models as a way to analyze the consequences of development of a patch of habitat (Boyce 1992). However, the citizen participants found this approach to be obtuse and excessively technical, requiring them to take 'on faith' the validity of models produced by experts. There was a strongly expressed sentiment among these non-technical members of our design team that they must be able to explain any analysis we used in a reasonable way to their fellow citizens, without relying on 'outside' technical expertise to establish the credibility of the analysis.

A second lesson is that scientists are challenged to establish and maintain scientific credibility in public processes. While it is improving, there remains a disparity between information that scientists produce and the information needed in local land-use planning. This shortfall was most evident when we attempted to move beyond broad scientific principles to implementation and application of these principles. For example, a literature base on which to parameterize the distance for neighborhood richness is simply lacking. However, because land-use decision making will not wait for scientists to 'get it right,' the urgent need compelled us to estimate a reasonable value.

In the face of limited scientific information, the key is to provide a rational, explicit basis on which to make decisions. Rejeski (1993) found four issues that are particularly important in establishing scientific credibility in public processes. Data and analyses must be believable, that is, they must provide a reasonable, faithful representation of the places where people live. They must be honest – all uncertainties must be conveyed to users. They must be useful in the context of the decisions they were designed to support. And they must be clear – all predictions and abstractions, particularly maps, must be understood by the public affected by them. Our experience amplifies the statement by Holling (1997: 3) that 'We prefer approximate answers to the right questions, not precise answers to the wrong questions.'

A third important lesson is that planning for conservation is a process that uses scientific data, but that ultimately depends on the expression of human values. Science can help inform citizens about the basic patterns and processes of natural systems, but citizens must express personal values to determine which endpoints are most desirable. Scientists should not offer answers. Instead, they should press citizens to articulate their values and goals for the landscapes where they live. Clearly defining their goals for conservation enables scientists to select more appropriate scientific data and models to support the choices for seeking those goals. Thus, in the context of local decision making, the success of a model should not be measured by its ability to make accurate predictions, but rather by a user's ability to make and communicate the basis for a decision relative to a clearly articulated goal.

A fourth lesson is that efforts such as SCoP require frequent and ongoing interaction with system users. Design of the prototype system required over a dozen meetings over the course of two years, and funding for the core staff of four was roughly $200,000. The strength of the project, however, stems from this investment in the collaborative design process. For example, the interface design is founded on the real-life experience-base of our users, not on our interpretation of their needs. Expanding to other counties and administrative units is minimal now, however, by inserting county-specific data into the overall application. As we transition from prototyping to implementation we find it difficult to maintain constructive feedback from our users. We need to move beyond simply disseminating information and continue to improve the system by incorporating constructive critiques, to learn from positive and negative experiences, and to gain important feedback.

Perhaps the most compelling argument we could make about the value of applying biological information to land-use decisions is that such information enhances choices, and in so doing, provides ground-level conservation. It remains too early to make this argument. Incorporating biological information into local land-use planning, particularly through the use of geographic information systems has been heralded loudly, but little research exists that evaluates how biological information has influenced a land use decision. How has the outcome of choices been altered by information? Has the debate during the planning process been improved? Does having information readily available change the constituency involved in the decision-making process? More research needs to evaluate the results of such efforts in order to understand how we as landscape ecologists can improve our science in support of conservation planning.

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