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Integrating Sustainable Development and Environmental Vitality: A Landscape Ecology Approach

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Abstract

Opportunities for sustaining humans and their environmental systems can be enhanced by examining how socioeconomic and ecological processes are integrated at the landscape level. Landscape properties—such as fragmentation, connectivity, spatial dynamics, and the degree of dominance by habitat types—are influenced by market processes, human institutions, and landowner knowledge as well as by ecological processes. These same landscape properties affect ecological processes that influence species abundance and distribution, as well as the production of goods and services valued by human society. An approach for understanding these complex interactions includes models that simulate (1) land use changes that alter landscape pattern, (2) effects of landscape pattern on species persistence, invasion of exotics, and resource supplies, and (3) dynamic interactions involving possible feedback processes that can alter land uses or landscape patterns. Adaptive management is recommended for using this approach to attain sustainable development where ecological processes operating at micro, meso, and macro scales are integrated.

Key words. Sustainability, landscape ecology, socioeconomic processes, ecological effects, modeling.

Introduction

The most important challenge facing environmental management is to create and foster a balance between human needs and environmental sustainability (Ruckelshaus 1989, Lubchenco et al. 1991). Sustainability is defined as the process of change in which the continued exploitation or protection of resources, the direction of investment in land, and associated institutional changes are consistent with future as well as present objectives for perpetuating en-

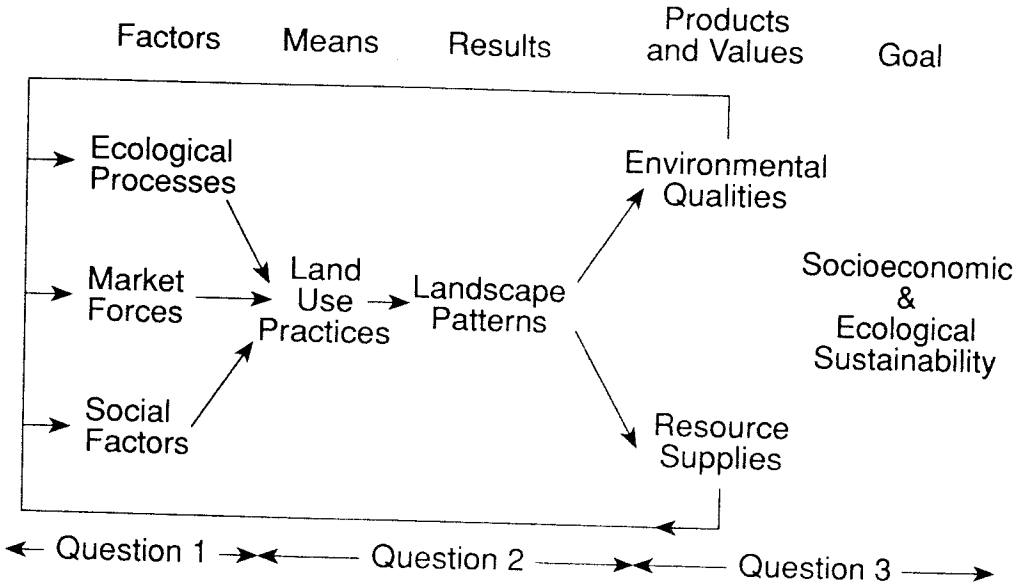

FIGURE 20.1. Processes affecting socioeconomic and ecological sustainability. Sustainability is achieved through the maintenance of acceptable environmental qualities and resource supplies. Ecological processes, market forces, and social factors affecting land use practices are altered by feedback from environmental qualities and resource supplies.

of environmental sustainability. Dynamic processes are represented by feedback loops.

The processes addressed in the first question are modeled separately and are integrated sequentially, beginning with social factors and culminating with a simulation model that uses social, economic, and biophysical information to assign probabilities of transition for land uses. Additional models are used to simulate the effects of changes in landscape patterns on environmental qualities and resource supplies. An adaptive management approach is recommended for answering the third question. Adaptive management involves the use of an experimental or quasi-experimental logic for management problem solving (Holling 1978, Walters 1986).

Influence of Economic and Social Factors on Landscape Structure

Landscape structure is a function of land use, and land use is influenced by social, economic, and environmental factors. We will first examine the economic and social factors driving land use and then discuss their use in models to simulate changes in landscape structure.

Socioeconomic Factors

While changes in ecological processes such as species persistence are outcomes associated with landscape change, social and economic considerations are among the most important drivers of landscape change in the temperate zone. Economic motivations affect the relative values that landowners place on the products and services obtained from their land. Shifts in these values often result in altered land use (Samuelson 1983). For example, this theory would suggest that increases in relative crop prices might encourage some landowners to clear forested land for agriculture, while rising housing prices might prompt a landowner to convert forested land to residential use. Relative values are complex measures influenced by markets; institutional, biophysical, and locational factors; and landowner characteristics and knowledge (Bartik 1988, Brooks 1987).

Markets

Markets are the pricing mechanisms for many important products of land management. The market-determined prices, combined with the costs of management (largely determined by locational factors), define the net returns or rents accruing to the various land uses. In the absence of nonmarket considerations, land will tend to be placed in high rent uses (Clark 1973). In forested landscapes, for example, timber, recreation, and agricultural markets have a critical bearing on the potential return from alternative uses of land (Alig 1986, Parks 1991).

Institutional, Biophysical, and Locational Factors

Institutions are cultural structures such as governmental agencies, interest groups, and the body of laws and policies governing land and resource use. Institutions may influence the discretion of the landowner directly through mechanisms such as zoning and land use regulation. Or they may influence decisions indirectly by altering conditions affecting land rents or, as in the case of public agencies, those affecting budgetary capability (Repetto and Gillis 1988). For example, subsidies for reforestation increase rents accruing to forestry uses, whereas agricultural subsidies may favor planting certain crops. Tax structures that tailor land to specific uses also alter relative land rents. Regulations may protect the habitat of an endangered species or the quality of water entering a stream or aquifer. Institutions affecting land use are a product of processes such as social movements and governmental policy making (which involves interaction among legislative, administrative, and judicial branches of government).

Biophysical attributes determine the potential production from a tract of land (Palmquist 1989). These attributes include soil type and structure, hydrology, vegetative cover, animal habitat, and slope and aspect. For example, slope in conjunction with hydrology defines the stability of the soil,

and therefore the sustainability of production under various forms of management. Vegetative cover, such as forest, may tend to remain unchanged because of prohibitive land-clearing costs.

An important attribute for determining land values is the location of a tract relative to cultural and biophysical features (e.g., Thunen, cited in Samuelson 1983). The distance between a tract and the market for its products defines transportation costs. Distances to services (e.g., sewer and water, shopping, a medical center) characterize the relative isolation of a tract, and thus its value for real estate development (Alonzo 1964). Use of adjacent lands also influences management decisions on a particular tract, especially when neighboring lands are developed for residential uses.

Landowner Characteristics and Knowledge

The worth of products and services obtained from the land is influenced by the values, management objectives, and life-styles of landowners (Bartik 1988). Income and budget constraints sway land use decisions as well. For example, compare a landowner engaged in subsistence farming with one who is dependent on a relatively high retirement income. The value to these owners of game products derived from the land might differ considerably. Similarly, one public landowner may be driven by a mandate to generate revenue by cutting timber from state trust lands, while an adjoining public owner may be guided by objectives emphasizing the preservation of original forests, such as a national park.

Land use decisions are also influenced by the extent of the landowner's knowledge about the land's physical capabilities and the relevant product markets. Knowledge about biological systems and markets is distributed unevenly within a society. Landowners and managers may often know more about the biological and management possibilities of their lands than the researchers who are responsible for increasing scientific knowledge (Padoch 1986). Although it is often ignored in economic analysis, landowners behave differently depending on the degree of their knowledge about the land. The length of time that owners or managers have worked with a parcel of land can have a direct bearing on how much they have learned about its characteristics and uses (Chandler 1990); absentee owners are expected to have less knowledge than residents. It is possible to separate landowners or managers into categories of those who are knowledgeable about their lands, its possible uses, and the markets for its products, and those who are relatively uninformed.

Methodology

Calculating Transitional Probabilities

The socioeconomic factors discussed above can be incorporated in models to simulate the propensity of land to change from one use to another. The extent of landowner and manager knowledge can be measured by using

methods developed in cognitive anthropology and applied to cultural ecology (Spradley 1979). These methods are derived from systematic interviews of landowners and managers with the purpose of quantifying the amount and accuracy of their knowledge and its influence on their behavior. The remaining economic and biophysical data can be acquired from existing maps and data bases and will involve time series analyses.

The influence of the socioeconomic factors can be simulated by modeling the propensity of a patch of land in a specific use to change to another use (or remain in the same use) as a function of several driving variables. This analysis involves modeling land use shifts between time periods in probabilistic terms by using limited dependent variable approaches (e.g., Parks 1991). These approaches are used to describe the influence of selected explanatory factors on the conditional probability of choices among a limited number of alternatives. The equation representing these conditional probabilities is:

$$P_{ij} = \Pr(Y_{ij} = 1/X)$$

where P_{ij} is the probability that land will change from use i to j; Y_{ij} is a binary variable that takes on the value 1 if the tract moves from use i to use j ($Y_{ij} = 0$ otherwise) within the measurement period (Pr is a probability operator); and X represents the vector of socioeconomic factors described previously.

A cumulative distribution function for the change in land use is estimated. The results of these estimations can be evaluated by using standard t-tests to assess the influence of the X-variables on decisions and to provide transition probabilities for land, social, and economic conditions. These transition probabilities are used to drive the landscape-change simulations. Simulations reflecting changes in economic and social conditions are accomplished by altering the values of the driving variables, recalculating transition probabilities, and driving the landscape change simulation model with these new probabilities.

Simulating Landscape Change

Projecting regional patterns of land use and land cover requires integrating the transitional probabilities calculated above with existing land cover patterns. Given a map of existing land cover patterns, the land use transition probabilities are distributed spatially depending on the economic, social, and physical characteristics of each land parcel. The linkage of these probabilities to the spatially explicit data base, such as is stored in a geographic information system (GIS), allows changes in a landscape through time to be simulated. Alternative scenarios can be explored, and the relative importance of different controlling factors evaluated. Thus far, this approach has been applied only to a limited extent but appears promising (Turner 1987, 1988; Naiman et al. 1988, Parks 1991).

Impacts of Landscape Change on Environmental Quality and Resource Supply

Since environmental integrity and resource supply are intimately tied to the structure of landscapes, changes in the landscape inevitably affect the ecological properties of the environment and the abundance and quality of resources produced.

Environmental Quality

The ecological implications of land use change are numerous because landscape patterns influence a variety of ecological processes (Turner 1989, Naiman and Décamps 1990). For example, plant succession, biological diversity, foraging patterns, predator-prey interactions, dispersal, nutrient dynamics, and the spread of disturbance all have important spatial components at broad spatial scales (Huffaker 1958, Holling 1966, May 1975, Peterjohn and Correll 1984, McNaughton 1985, Turner 1987, Senft et al. 1987, Burke 1989, Hardt and Forman 1989, Turner and Gardner 1991). We address one particular ecological response: species persistence as an indicator of environmental quality. We begin with a general discussion, then address indigenous and exotic species.

Species Persistence

The persistence of species is influenced by the number, size, and geographic arrangement of patches across a landscape (Forman and Godron 1986). Thus land management for the maintenance of a particular species may require the protection of habitat patches of a particular size and juxtaposition. An alternative management or conservation goal may be to perpetuate natural fluctuations in the landscape mosaic (e.g., resulting from a natural fire regime), implying that the abundance of certain species will fluctuate as well. The connectivity of habitat is often of particular importance, and several studies suggest that landscapes have critical thresholds in habitat connectivity at which ecological processes will show dramatic qualitative changes (Gardner et al. 1987, Krummel et al. 1987, O'Neill et al. 1988, Turner et al. 1989, Gosz and Sharpe 1989, Rosèn 1989, Naiman et al. 1988, Johnston and Naiman 1990). Changes in a landscape that is near a threshold may strongly influence species persistence. For example, habitat fragmentation may progress with little effect on a population until the critical pathways of connectivity are disrupted; then a slight change can have dramatic consequences for the persistence of the population (Gardner et al. 1991, Turner et al. 1991). In addition, changes in habitat connectivity can influence the susceptibility of a landscape to disturbance, such as the spread of an invading organism. Therefore, if the long-term maintenance of biological diversity is a conservation goal, a land management strategy that emphasizes

regional biogeography and landscape patterns may be necessary (Noss 1983, Noss and Harris 1986).

Indigenous Species

Concern over the persistence of indigenous species is reflected in the increasing attention given to maintenance of biodiversity (Noss 1989, Lubchenco et al. 1991). Although biodiversity is difficult to define, and even more difficult to measure, diversity of species is conceptually simple and ultimately measurable. Destruction or disturbance of habitat is a major cause of threats to species persistence or species loss (Fahrig and Merriam 1985, Noss 1987, Harris 1988, Yahner 1988, Lord and Norton 1990, Quinn and Harrison 1988, Wilcove 1987). Fragmentation of the landscape has resulted in a loss of communities, the creation of abundant edge habitat at the expense of interior habitat, the alteration of natural disturbance regimes, and the loss of variability of ecological processes over broad spatial and temporal scales.

We now realize, for example, that because habitats for many species occupy areas larger than ecological communities and sites, a landscape approach is necessary to understand how habitat disturbance affects species persistence. The efforts to preserve the northern spotted owl (*Strix occidentalis caurina*) illustrate how some species may require maintenance of suitable habitat conditions over large landscapes (Thomas et al. 1990).

Many species appear to require the relatively undisturbed habitat conditions found in national parks, wilderness areas, old-growth forests, or mature second-growth forests (Carey 1989). These areas often contain landscapes large enough to provide the ecological patterns and processes needed for their survival. Perpetuation of species may require continuity in the natural cycles of disturbance which characterized the development of these landscapes and their dependent species over evolutionary time. These areas constitute ecological refuges within larger landscapes subject to disturbances accompanying the production of timber, agricultural crops, or residential and commercial development.

Suitable habitat conditions can often be maintained on lands used for commodity production or recreation if essential vegetative characteristics and landscape patterns are provided (Franklin and Forman 1987, Naiman et al. 1991). Landscape connectivity is important for species that require advanced seral stages for purposes of migration from one large patch to another; and animals such as deer (*Odocoileus* spp.), elk (*Cervus elaphus*), and anadromous fishes (e.g., *Salmo, Oncorhynchus*) require migration corridors relatively free from residential development or other obstructions to their movement between habitats (Naiman et al., this volume; Stanford and Ward, this volume). Cavity nesting birds can be perpetuated by leaving snags in forests where harvesting would normally require removal of such safety or fire hazards (Oliver et al., this volume; Franklin, this volume).

The impact of organisms on the environment is well known. Vegetative cover and individual species influence soil characteristics by the production of litter and by activities associated with roots; they affect water yield and qualities via evapotranspiration and soil-nutrient interactions; and they even influence climate by their abilities to regulate heat and water fluxes. Similarly, animals exert long-lasting controls on ecological systems by direct habitat alterations and by their foraging strategies (Naiman 1988). Feeding strategies and physical environmental alteration affect plant and animal community composition and biogeochemical cycling and nutrients in soils and water. These changes are important because they reverberate throughout the food web, causing alterations to the ecosystem that cannot necessarily be anticipated with current knowledge and technology. Examples are found in ecosystems undergoing sustained anthropogenic alterations (Zaret and Paine 1973, Vitousek 1986, Thomas et al. 1990).

Exotic Plant Species

The invasion of nonnative species may be the most pervasive influence affecting biodiversity in many systems (di Castri 1990, Coblentz 1990). Exotic species frequently displace native plant or animal species, and thus alter the ecological dynamics of an area. They may even alter ecosystem structure and function. The invasion of the Atlantic shrub *Myrica faya* in Hawaii demonstrates the impact an exotic may have. *Myrica faya* has invaded extremely nitrogen-deficient sites of Hawaii Volcanoes National Park. By actively fixing nitrogen, this plant has altered nutrient cycling, productivity, and primary succession in this region (Vitousek 1986). In California, the exotic ice plant *Mesembryanthemum crystallinum* has altered the physical and chemical properties of the soil by concentrating salt from throughout the rooting zone onto the soil surface (Vivrette and Muller 1977). Numerous other examples of alteration of ecosystem properties by exotics have been documented (Vitousek 1986).

Exotic species typically thrive in highly disturbed or managed environments (Baker 1965, Forcella and Harvey 1983, Fox and Fox 1986, Heywood 1989, Rejmanek 1989), which are often located adjacent to parks and other natural preserves. Hence parks and preserves may be adversely impacted by the invasion of exotic species from adjacent disturbed or managed lands. Once established at a site, an invading plant can disperse to other nearby locations. Thus the distribution, abundance, and juxtaposition of colonized patches and potential sites all influence the movement and establishment of exotics. There are three fundamental questions that concern exotic species from our perspective: (1) What features of the landscape are more susceptible to colonization? (2) What features serve as long-term or ephemeral sites for the establishment of exotics? (3) What features serve as corridors for movement of these species?

A landscape-level perspective addresses source areas (i.e., where exotic species are well established), and potential colonization sites. Source areas

must be evaluated for (1) number, diversity, and abundance of exotic species present, (2) the spatial distribution of source patches across a landscape, and (3) the length of time the area serves as a source. Potential colonization sites must be evaluated for (1) susceptibility to invasion, (2) proximity to source areas, and (3) regional and local disturbance regimes that alter susceptibility to colonization or establishment. By considering patches as sources and potential colonization sites, and corridors as paths for movement of exotics, managers can interpret land use practices in terms of increasing or decreasing landscape susceptibility to invasion by exotics with contrasting life history and colonization strategies.

Resource Supply

The design and maintenance of landscape patterns conducive to the perpetuation of desirable ecological processes can significantly affect opportunities for producing resource supplies. For example, the conservation strategy to protect the northern spotted owl may reduce timber harvesting on federal lands by as much as 23% (Thomas et al. 1990, Interagency Economic Effects Review Team 1990, Lippke et al. 1990). Additional regulation of timber harvesting on private land may be necessary to maintain migration corridors for dispersing owls. Reductions of this magnitude over a few years can be socially and economically devastating to people who live in relatively isolated communities dependent for jobs and income on wood resources (Lee 1990). The rate and magnitude of this change may exceed critical thresholds of human adaptability, resulting in a loss of socioeconomic sustainability for people living in local settlements (Fortmann et al. 1990, Lee et al. 1991). Conservation strategies for other species requiring the maintenance of large-scale landscapes could have similar regional or local human impacts. Development activities such as dam construction, rapid timber harvesting, and residential development can also interrupt socioeconomic sustainability by disrupting the habitat upon which people depend for their livelihood (Paine 1982, Muth 1990, Bradley 1984).

These conservation and development activities may simply replace one sort of human habitat with another. Unlike other animals, humans are relatively adaptable to a wide variety of environments and are unique in their ability to consciously transform landscapes into habitats that suit their needs, including the long-term need for a sustainable life support system. The absence of biologically programmed habitat requirements makes it possible for humans to adjust to constraints imposed by the lesser adaptability of other species and natural ecological systems (Berger and Luckmann 1966). However, human adaptability is governed by social and cultural processes that constrain both the rate at which people can accommodate to habitat change or create new habitats and the geographic scale of change that they can accommodate without major social and economic disruptions (Goldschmidt 1990, Lee 1991, Firey 1960). Hence the maintenance and regulation of eco-

logical processes at the landscape scale will involve reinstitutionalizing the temporal and spatial organization of patterns of behavior long geared to the availability of agricultural fields, timber stands, homesites, campsites, or individual plants or animals.

Analysis of human responses to landscape structure is complicated both by the role humans play in structuring their environments to suit their needs and by the fact that their habitat requirements are defined by their culture rather than by genetic programming (Berger and Luckmann 1966). Moreover, humans are capable of satisfying their material needs by exchanging goods and services on a global scale rather than just locally. The challenge for resource managers is to find how the goods and services needed by society can be produced while also progressively building and maintaining the landscape patterns that will ensure perpetuation of essential ecological processes (Firey 1960, Lee 1991, Franklin and Forman 1987, Stanford and Ward, this volume). Land use decisions made with the goal of attaining desired goods and services can be evaluated in terms of their long-term environmental and socioeconomic impacts. For example, individual small and localized land use decisions occurring over several years appear insignificant at the landscape level. However, consideration of the ecological impact that these decisions could have in the aggregate could prevent landscape structure from crossing a threshold that would cause permanent and undesirable change.

Methodology and Feedback

The identification of landscape characteristics (e.g., patch sizes, habitat connectivity) that are particularly important to the persistence of a single species, indigenous species, or supply of a resource is necessary before effects of landscape change can be predicted. These variables can be identified by analyzing field data, or by performing a sensitivity analysis of a spatially explicit model. In the latter case, model simulations are conducted as landscape structure is varied systematically. Landscape characteristics that have a strong influence over the model's projections can be considered as landscape state variables for the species or resource of interest. Changes in the landscape can then be expressed as a trajectory through the state space. At any point, the landscape can be described by the values of each state variable. Figure 20.2 depicts such a diagram for a case in which three landscape state variables have been deemed crucial to the persistence of a species. Land use changes would cause the landscape to evolve through time along a path or trajectory that connects the current landscape to the future landscape.

Consider as an example a spatially explicit demographic model that predicts population size and number of local extinctions for a certain species. Given a particular management regime, one objective is to maximize the species' population size while still being within the state space defined by management options that consider both ecological processes and socioeconomic functions. The criterion used to select a path connecting the present

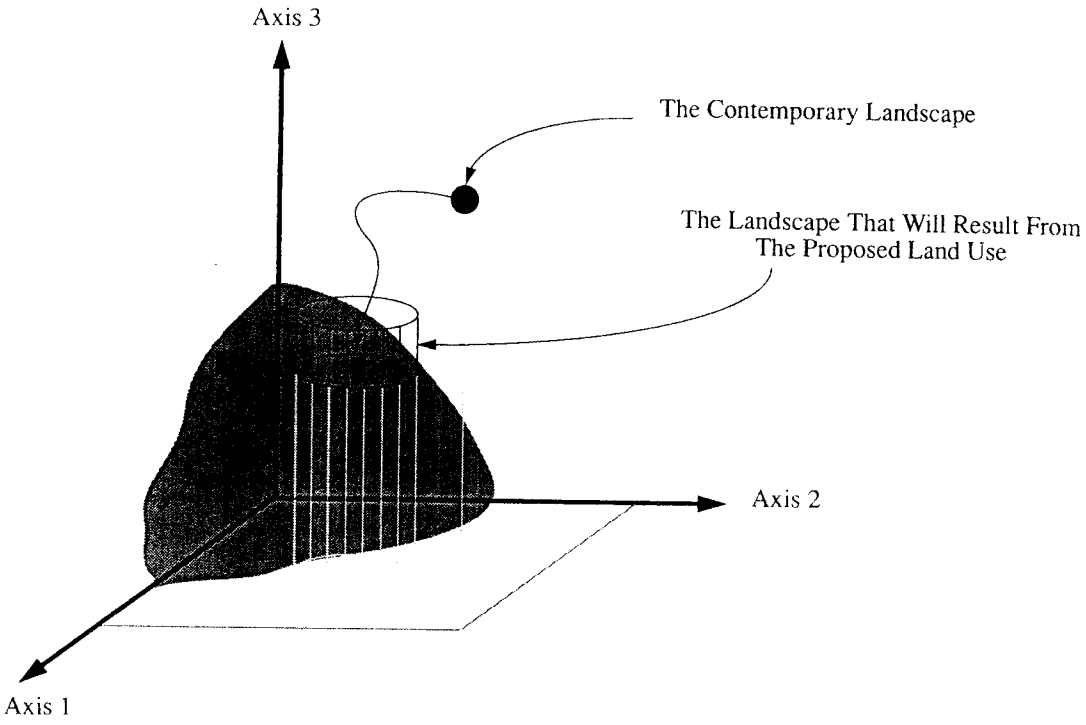

FIGURE 20.2. The contemporary and future landscapes within the landscape state space. The contemporary landscape is represented by a point, whereas the future landscape is represented as a region. Both the endpoint in this region and the path used to get there are variables that can be adjusted by changing the way land is managed. The gray region corresponds to an area of low species persistence. In this example, most of the future landscape would correspond to low species persistence. The path connecting the contemporary and future landscapes ends in the gray region, and would thus not be acceptable. A path connecting the contemporary landscape to the portion of the future landscape outside the gray region could be attained by altering land use pattern.

and future landscapes might be to minimize the number of local extinctions expected during the management period. Using the demographic model, regions of state space could be identified that were unsuitable for the species under study. These regions could then be plotted and, in the case of a three-dimensional state space, the results might look something like the shaded area in Figure 20.2. The results of the optimization could be used in planning land management activities (e.g., timber harvesting patterns). Management regimes that would prevent the landscape from taking excursions into the portion of state space deemed unacceptable for species persistence could be determined. This entire analysis could then be repeated for other species that operate at different scales or trophic levels in the landscape. Landscape trajectories could thus be identified with the highest probabilities for not threatening any of the species under study yet providing resource flows needed to sustain socioeconomic functions. If the species to be studied were chosen so that together they formed a good indicator of the health of the community,

conclusions could be drawn about the impact of land use on a community of organisms inhabiting a managed landscape.

The landscape trajectory can be evaluated as a feedback process. Society responds to the state of the landscape and external socioeconomic factors by making land use decisions. These decisions result in the construction of a new landscape, and therefore movement in the state space. This new landscape, with its own set of attributes, affects future land use decision making, just as the original landscape did. The changed landscape may alter future land use decisions by changing socioeconomic functions and causing changes in policies governing landscape management. This inherent feedback process permits the examination of long-term effects of present land use decisions.

A Knowledge System Environment for Integrating Interdisciplinary Modeling

A versatile methodology is essential when seeking to integrate qualitative and quantitative knowledge describing diverse biological, physical, social, and economic processes. One methodology that is designed to integrate knowledge, regardless of its origin or form, is artificial intelligence (Borrow and Collins 1975, Hart 1986, Charniak and McDermott 1987, Luger and Stubblefield 1989). An environment where information is integrated is called the knowledge system environment (KSE) (Coulson et al. 1989).

Modeling Systems

Knowledge integration can be accomplished by using two artificial intelligence techniques: knowledge representation and search (Saarenmaa et al. 1988). Knowledge representation is the form in which each piece of information is stored in the computer. In the KSE, these forms include answers to system queries via a user interface, tabular and spatial information stored in a data base, analytical and simulation models residing in a model base, spatial analysis routines operating within a geographic information system (GIS), and qualitative information organized as a knowledge base. Search is how the information is processed. A search algorithm can be viewed as a path between a problem and a solution and typically is defined in the knowledge base. Along a search path are questions that must be answered before the solution is reached. The specific path taken is defined by the problem posed, the information gathered, and the order in which the information is compiled. Knowledge is ultimately displayed spatially as a map. Pixels or patches on the maps are represented as objects and have assigned to them attributes (such as land cover type, ownership, and transitional probabilities) collected during a search algorithm (Bobrow and Stefik 1986). Search

paths conclude with the assignment of attributes to pixels or patches that represent the solution, and the production of a map.

A system to project and evaluate landscape changes is shown in Figure 20.3. Each representation of knowledge is stored in one of the system's components. The general solution algorithm represents the universal search path. A single iteration in a simulation involves two steps: (1) estimation of landscape change, and (2) prediction of the ecological effects of the landscape change. The final product of both analyses is a map which is entered into the data base for subsequent simulations or examinations of feedback processes.

The analysis of landscape change involves two knowledge bases. The first houses the search paths used to evaluate the socioeconomic factors that affect land use decision making. In these paths, transitional probabilities for land use or land cover type are calculated and then assigned as attributes to each pixel or patch in the map. In the second knowledge base reside the paths used to apply the transitional probabilities to the simulation of landscape change. The result here is a map of land cover that includes all the transitions in cover type caused by changes in land use.

The ecological-impacts-of-landscape-change knowledge base contains the search paths used to integrate the simulated landscape produced above with information gathered from the other system components for the purpose of analyzing ecological impacts. The information assembled during a simulation is specific to an ecological classification, such as an endangered species or water quality. Again, the information collected during the search process will be represented as attributes for each pixel or patch. The map produced can illustrate changes in some ecological variable (i.e., increase or decrease in diversity) or show abundances or distributions of the ecological classification.

Only a few modeling systems have been developed that integrate the human reasoning applied to land use decision making with the ecological implications of landscape change (Grainger 1986). The way knowledge is represented and searched for is unique to each problem and is not necessarily superior in any one system. There are, however, distinct advantages in incorporating qualitative knowledge to simulation problems that traditionally were solved using only numerical methods (Raman 1986, Saarenmaa et al. 1988). These advantages are: (1) hypotheses about the dynamics and implications of landscape change can be evaluated by developing mechanistic models of ecological processes and their socioeconomic drivers; (2) event-driven rather than time-driven models can be constructed; and (3) the knowledge base can be easily modified to allow for reasoning about alternate situations (such as predicting the behavior of the system with the introduction of a new landowner type or ecological characteristic, a change in the value of a resource, a change in government regulations, or a change in landowner heuristics).

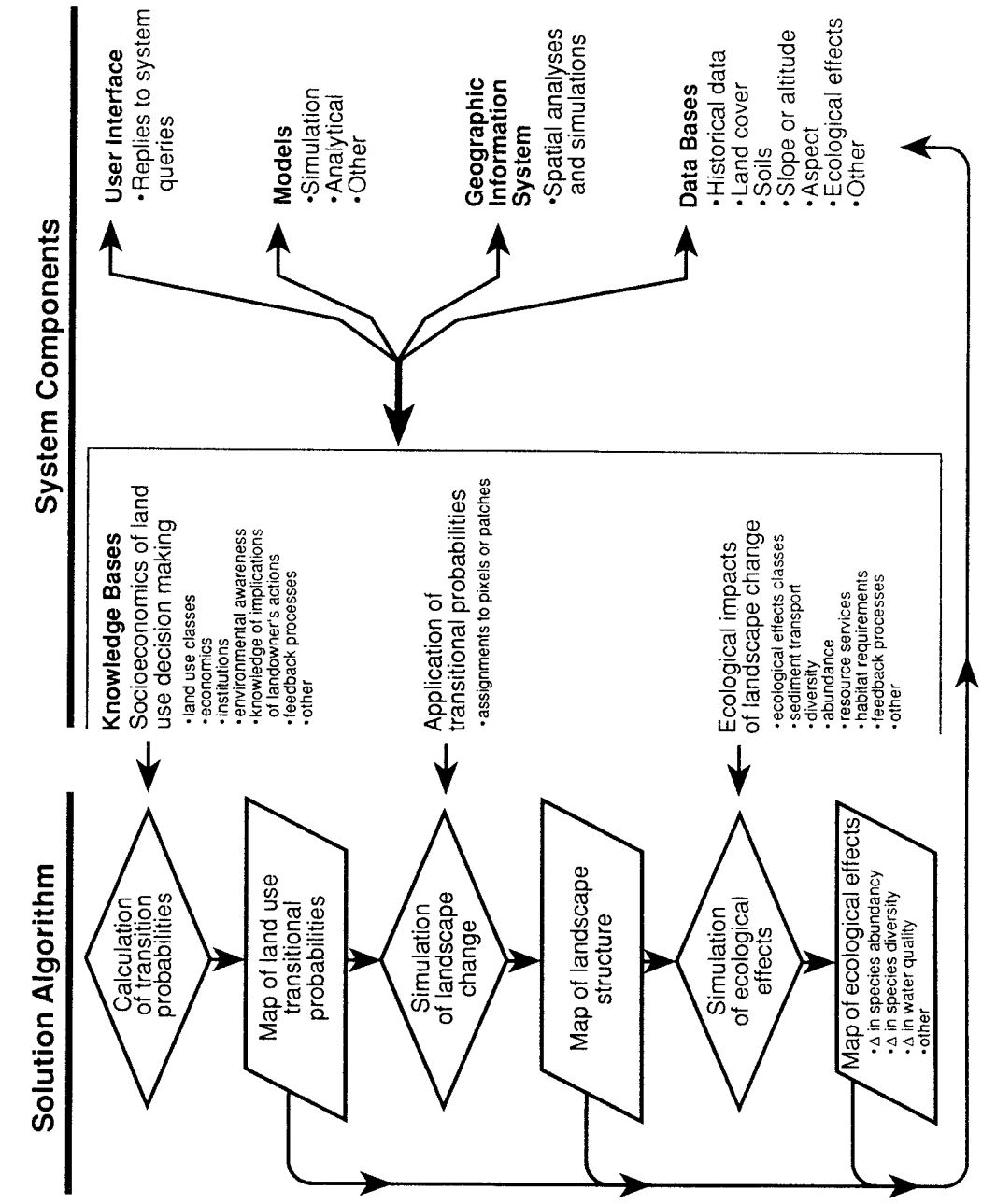

FIGURE 20.3. Schematic of the basic components of the modeling system, their linkages, and the general solution algorithm. Diamonds represent simulations and parallelograms are system outputs.

The disadvantages of including qualitative knowledge are that (1) it is difficult to create a comprehensive set of rules that describe a domain; (2) the rules are not based on an objective and predictable set of assumptions (e.g., erroneous conclusions may be reached when rules are not observed); and (3) although the inclusion of qualitative knowledge into a landscape simulation increases our understanding of the system, explanations derived internally may only restate what is already known. As with pure mathematical simulations, however, additional explanations can be provided by expertise outside the system.

Processing Feedback Loops

The present state of the landscape is a function of previous land use decisions. Simultaneously, the socioeconomic factors impinging on land use decisions are, in part, a function of the existing state of the landscape. This feedback, a critical component used to explain landscape sustainability, is addressed by the modeling system as follows. Within each iteration of a simulation, three maps are produced (Fig. 20.3). As the maps are produced, they are inserted into the data base. These maps are available for use in calculating the next iteration's set of transitional probabilities. This new set reflects the influences the landscape has on socioeconomic functions (i.e., the feedback on land use caused by changes in resource supplies and environmental qualities). This feedback loop can be iterated several times to examine the long-term effects on the landscape from alternative land uses driven by socioeconomic factors. These iterations take the form of multiple paths through the landscape state space. It is this process that provides the foundation for developing a socioeconomic and ecological sustainability.

Achieving Socioeconomic and Ecological Sustainability

Developing an understanding of how ecological processes respond both to landscape pattern and to changes in the landscape will aid in the identification of landscape configurations that are sustainable (Forman 1988). Sustainability implies a relatively long temporal scale (several human generations), a recognition of change in social and environmental systems, and the incorporation of basic human and environmental needs (Ruckelshaus 1989).

One approach to evaluating the long-term implications of alternative landscape configurations is to quantify selected social and ecological responses to various combinations of landscape variables, as represented in the state space model. This approach would permit an evaluation of the effects of landscape patterns, as they change through time, on parameters of social or ecological interest. Given the complexity of the socioeconomic-ecological interactions that we face, the development of aggregated measures of sustainability remains a crucial task.

Moreover, sustainable development requires an approach to science that involves inventing desirable futures (Jacob 1982, Medawar 1982). Science alone cannot tell us what to do to sustain ecological and societal systems, because of the importance of choosing desired conditions. Such choices are inherently social and must involve the people affected by environmental management decisions. Hence the complexity of implementing sustainable development defies the normal scientific process of using hypothesis testing as a primary tool for prescribing actions. Instead, we recommend an interactive approach to goal seeking and monitoring of consequences in which working hypotheses are formulated, tested, reformulated, and retested through an adaptive management strategy (Holling 1978, Lee and Lawrence 1986, Walters 1986). In this way science can serve as an instrument for development without imposing scientific prescriptions in place of social choices.

Conclusions

As this chapter has shown, there is much to be learned about sustaining humans and their environmental systems by focusing on ecological processes that operate at the landscape level. Landscape analysis can facilitate discovery of interactions between socioeconomic and ecological processes that were not clearly discernible when examining individual ecological processes and socioeconomic systems in isolation. Human production of necessary goods and services from lands has readily measurable impacts on ecological processes at the landscape scale that often are not evident when attention is focused on specific sites. Models that estimate land use transition probabilities appear to be effective means for analyzing anthropogenic changes in land cover that affect landscape pattern in ways not detected by focusing on smaller scale ecological processes. Similarly, modeling of the relationships between landscape patterns and environmental quality or resource supplies can show how larger scale ecological processes affect species persistence, the invasion of exotics, and the provision of goods and services used by humans.

However, landscape analysis can be just as limiting as the focus on sites, stands, and ecological communities. Attention also needs to be given to the scale of major biogeographical regions and continents to anticipate and detect acceleration of ecological disruptions in one region or continent when landscape-level regulations constrain land uses or resource production in another country or political jurisdiction (Lippke et al. 1990). For example, given no reduction, or steady increases, in demand for wood products on a global scale, reductions of wood production in the Pacific Northwest may indirectly contribute to accelerated harvesting of forests in Siberia or another region with available wood supplies and less concern for conservation. Regulations designed to conserve landscape-level ecological functions in one

region may have the unanticipated consequence of contributing to far greater losses of biological diversity and sustainability in another.

Landscape ecology emerged as a means for understanding the cumulative effect of individual land use decisions on ecological processes operating on a larger scale. Site- and stand-level ecological disturbances accumulated over time and space to have major unanticipated effects on landscape processes. Landscape analysis must develop methods for anticipating the regional and global effects of prescribing landscape patterns that may make ecological sense at the landscape scale. To help attain sustainability of environmental qualities and resource supplies, scientists must learn how to integrate analysis performed at micro, meso, and macro scales. This article has shown how progress can be made in studying sustainability at the meso scale. Further work is needed to develop methods for integrating such landscape analysis with the macro scale. The focus will need to be the global ecological processes (especially atmospheric pollution and biogeochemical cycling), human population growth and distribution, human sustenance activities, and the human ecology of energy and material flows.

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