Linking Land-Use Science to Decision Making: Strategies and Opportunities

Virginia Dale
Corporate Fellow
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6038

Abstract:

Land-use science provides the scientific information needed to inform and advise the decision-making process by considering, at several scales (populations, ecosystems, and biomes), the effects of changing the condition of the land. Integrating land-use-science research results with decision making enhances understanding of the underlying processes and of the implications of management. In such an integration, a systems perspective can identify the most effective management actions and common grounds for stakeholder groups. In addition, management actions can be treated as experiments that provide future management guidance in selecting the most effective management options for minimizing the impacts of land-use change and for taking advantage of opportunities under the new land-management policies. Often, management that adopts an ecosystem perspective rather than an organismic perspective provides better options because land management changes species demography and diversity, juxtaposes different land covers, produces disturbance regimes, and alters biogeochemical cycles. Land-management plans may address (1) the system prior to the change, (2) the change itself, (3) the system immediately after the change, or (4) the recovery process. Where ecological systems are intact and near their original status, land-management and policy decisions can be designed to enhance resilience or resistance. Because reclamation or restoration is costly and difficult to implement successfully, proactive steps to reduce negative environmental effects may be the most effective strategy. By careful site selection and design, strategies can be developed to take advantage of natural features while reducing adverse impacts. Where land use and management have degraded ecological conditions, coping strategies should promote ecological restoration and mitigate further harmful impacts even though restoration to the original ecological state may be impossible. In all cases, ecological understanding in land use and management should be based on scientifically sound ecological principles.

Keywords: Communication, decision makers, land use, systems science

Introduction

Land-use science provides the scientific information needed to inform and advise decision-making processes involving changes to the use or condition of a land area. Such changes often influence ecological processes at multiple levels of the biological hierarchy of organization (*populations*, *ecosystems*, and *biomes*). Therefore, it is useful to consider effects at several scales, ranging from the microscopic to the macroscopic, the organism to the landscape.

Within the different levels of organization, *population-level processes* include phenology, reproduction, and death, and they are influenced by human activities like fertilization, irrigation, weeding, and breeding. *Ecosystem-level processes* include disturbances, nutrient cycling, production, water use, succession, and competition, and they are affected by human activities like land management, pollution, pest outbreaks, and control of disturbances (e.g., fire). *Biome-level processes* include evolution, extinction, and migration, and they are influenced by plant breeding and broad-scale land management.

The specialized knowledge of land-use science thus has much to offer in informing, shaping, and optimizing decisions about land-use change and management. Scientists can contribute to such decisions not only by communicating information but also by building consensus, maintaining credibility, and discovering options for new policy and research directions (Dale 2002). Communication of information can occur via reports, web sites, seminars, workshops, field tours, press coverage, scientific papers, and many other channels. Scientists can help build consensus about the scientific understanding of and contributions to land management plans by sharing information, teaching, developing analyses, and participating in scientific advisory groups. Scientific credibility can be maintained by publication of peer-reviewed articles and engagement in debates about scientific hypotheses. Finally, scientists can be effective in exploring options through testing hypotheses, modeling, and adaptive management.

In cases where scientific information is used to inform and advise the decision-making process (e.g., see Dale 2002, Dale et al. 2005A), scientists and decision makers must communicate intensively so scientific perspectives can be a part of decision making. However, scientists and land managers or developers have different views of the world. Tieger and Barron-Tieger (1992) studied the personality characteristics of scientists and decision makers and found that most scientists are visionary and excel at creating systems, can understand complex and difficult subjects, enjoy creative and intellectual challenges, are good at theoretical and technical analysis and logical problem solving, work well alone, and are determined even in the face of opposition. However, scientists can also be less interested in projects after the creative problem solving is completed, may drive others as hard as they drive themselves, may be too independent to adapt to corporate culture, have difficulty working with or for others whom they consider less competent, and can be inflexible and single-minded about their ideas. Most decision makers, on the other hand, tend to promote harmony and build cooperation, respect a variety of opinions, are decisive and organized, and are natural leaders. At the same time, decision makers can also have trouble dealing with conflict, tend to sweep problems under the rug, may not be attentive to factual accuracy, or may take criticism too personally. Even though they have differences, scientists and decision makers must learn to communicate when policy questions involve science. Such questions arise in planning budgets, complying with federal environmental legislation (e.g., the Endangered Species Act), providing feedback on resource-management practices, and developing quantifiable resource-management targets.

Decision makers are often not aware that science can pertain to a policy issue. Regular discussions between scientists and decision makers can enhance communication and build mutual respect. The situation is complicated by the fact that scientific results are rarely expressed in terms that have meaning or value to decision makers. Both translating scientific results to particular conditions and extrapolating them beyond a specific study are challenging but necessary tasks to ensure the exchange of information.

At the same time, designing land-use-change research (a precursor to problem analysis and decision-forming recommendations) requires active collaboration among researchers and key decision makers, a focus on the appropriate scales of resolution, inclusion of all relevant disciplines and expertise, a "living" strategic plan of action, a commitment to the transfer of information and technology, and clear recognition of the uncertainties. For example, because trees are so long-lived and land-use changes occur so rapidly, forest research must combine modeling, experimental, and management approaches to be able to address complexities and scales of the challenge. Recognizing and adapting to the need for these new tools and techniques often requires a change in planning perspective.

A Systems Perspective on Land Management

Land-use changes can best be placed in the context of success and sustainability by adopting a *systems perspective* and an *engaged management approach*. Both of these techniques provide ways to improve one's understanding and management of factors affecting land-use change and its effects on ecological systems.

A *systems perspective* (a recognition of the different components of the environment and of their interactions) is useful to understand the inherent complexities of land-use change. Such an approach can assist decision makers in addressing land-use-change impacts in terms of research, management, and policy. It increases understanding of the role of feedbacks, how changes to any of the interactions can affect the overall system, and how perturbations to systems may result in a new level or type of stability. This perspective also helps identify (1) key pressure points for which management actions might be most effective or (2) positions that stakeholder groups may recognize as common ground.

A *management approach engaged with research* provides an appropriate way for decision makers to deal with the uncertainties inherent in land-use change. Management actions can be treated as experiments that test hypotheses, answer questions, and thus provide future management guidance. (Each phase of land-use change produces information that guides and informs decisions about subsequent phases.) This approach requires that conceptual models be developed and used and that relevant data be collected and analyzed to improve understanding as the system changes.

When all the causes and effects of land-use change are considered, the most effective management options can be identified to minimize the impacts of land-use change and to take advantage of opportunities under the new land conditions and land-management policies. Currently, these changes are producing strong regional trends in population, resource scarcity and quality (e.g., water), and pollution. Global changes include climate warming, a rise in atmospheric CO_2 concentration, increased ultraviolet radiation, desertification, resource depletions, reduction of the surface albedo of the Earth, sea-level rise, and the spread of invasive species. Land-use changes can both cause and be affected by changing disturbance regimes (e.g., fire and invading species). Management actions both respond to and affect land-use changes. They determine or respond to (1) the amount of resources to harvest and manage, (2) the means used to harvest and manage resources, (3) the estimation of supply of resources, (4) the estimation of demand for resources, and (5) the availability of access (e.g., transport routes).

Often, decisions that adopt an ecosystem perspective rather than an organismic perspective provide better options. Such a systems approach considers all plants and animals and the physical conditions of their environment as well as socioeconomic conditions (Holling 2001). Even a low-level (organismic) component of a land-use and -management practice can have a system-wide effect and must be considered when selecting strategies for expanding the range of favorable species or for containing deleterious organisms (Dale et al. 2005B). For example, the fungus that kills Port Orford cedar (*Chamaecyparis lawsoniana*) is spread by logging trucks, and harvesting activities in one portion of a forest can degrade or destroy resources throughout the forest. Fortunately, washing of logging trucks is an effective way to contain the fungus (Strittholt and DellaSala 2001, Jules et al. 2002) and can be included in land-management activities driven by an ecosystem perspective.

Ecological Effects of Land Use and Management

Environmental concerns related to land use and management are diverse and occur on a variety of scales. Dale et al. (2005B) identified four pathways by which land-use and management practices affect ecological processes: (1) demography and diversity, (2) land-cover juxtaposition, (3) disturbance regimes, and (4) biogeochemical cycles. These four types of changes often occur at the same time and interact with each other and with other stressors in such a way that, collectively, they can cause dramatic, nonlinear, and self-reinforcing changes. Said in another way, the effects of land-management practices are context dependent (Archer and Bowman 2002). Therefore, determining effects is not always straightforward, and management that is based on a single pathway may be inadequate.

Species changes

Land use and management can produce changes in population dynamics that may lead to local and selective extirpation or proliferation, introduction of new species, and changes in distribution. Elimination of local populations of a species can occur when land-use practices cause extensive mortality and/or prevent recruitment by altering habitat. For example, heavy grazing of rangelands by livestock or wildlife can shift the relative abundance of grasses, forbs, and woody plants, causing the local extinction of some species and a dramatic increase in others (Archer and Smeins 1991, Vavra et al. 1994). The spread of agriculture and agroforestry has resulted in the domination of cultivated regions by a few crop and tree species, and today, about 90% of the world's food comes from 15 crop plant species (Brookfield 2001). Management actions directed at a single species can cause unexpected changes in the abundance of other species and in ecological structure and function.

Changes in land-cover juxtaposition

Changes in land cover can alter habitat and the pattern of cover types. Habitat alterations typically occur with cropland conversions, urban expansion, logging, grazing, construction of dams, water-course alterations, etc. These alterations can make a site unsuitable for species that once occupied an area. For example, the presence of wolves (*Canis lupus*) is inversely related to road density (Mladenoff et al. 1995). As another example, in the eastern United States, the expansion of suburban areas and loss of forests has increased the area of forest edge and the proliferation of species that occur in forest edges [such as the native cowbird (*Molothrus ater)* (Chalfoun et al. 2002) and white-tailed deer (*Odocoileus virginianus*) (NPS 2007)].

Changes to disturbance regimes

Land-use and management practices can alter disturbance regimes, such as the intensity, frequency, and extent of fires, pest outbreaks, floods, and blow-downs. The disturbance regimes influence species richness and dominance (e.g., see Keeley et al. 2003) as well as ecosystem properties. For example, elimination of fires in systems that evolved with frequent surface fires have induced many changes in structure and function [e.g., oak savannas of the midwestern United States (Peterson and Reich 2001), ponderosa pine (*Pinus ponderosa*) forests of the western United States (Covington and Moore 1994), and longleaf pine (*Pinus palustris*) forests of the southeastern United States (Gilliam and Platt 1999, McCay 2000)]. Also, reductions in seasonal flooding have altered communities that once depended on these events (Johnson 1994, Friedman and Lee 2002). Knowing the conditions that foster disturbances and when and how to influence them is a challenge facing resource managers.

Changes to biogeochemical cycles

Land use and management affect the cycling of water, nutrients, and energy in many ways. Emissions of carbon dioxide, nitrous oxide, and methane have increased because of changes in land use and management, especially with industrialization and intensification of agricultural practices. These changes have affected air and water quality. Changes in vegetation structure alter pathways of energy flow and nutrient cycling. Even when a land-use practice is abandoned, its legacies may remain (e.g., plow furrows or livestock wastes can have long-term effects on the environment) (Bellemare et al. 2002, Foster et al. 2003). Land-management practices, such as grazing, forestry, and conversion to arable lands, affect trace-gas emissions because of alterations in the cycling of nutrients and in the distribution of organic matter. Land clearing, cultivation, and drainage of wetlands affect the cycling of carbon and nitrogen and enhance the mobilization of nitrogen from soil organic matter. Clearing land by burning off the biomass releases large amounts of carbon dioxide and reactive nitrogen to the atmosphere and contributes to recent changes in greenhouse gas fluxes from agricultural lands (Lindesay et al. 1996, Crutzen and Andreae 1990, Crutzen and Goldammer 1993). Deforestation and desertification are changes in physiognomy that alter biogeochemical cycles. Desertification results from extraction of water in excess of what a region can afford to lose and can lead to long-term change in water availability (Dregne 1983, Verstraete 1986, Schlesinger et al. 1990, Moat and Hutchinson 1995, de Soyza et al. 1998).

Dealing with Changes to the Land

Understanding and mitigating the negative impacts of land use and management on ecological processes offer many challenges and opportunities. Challenges can be met by considering potential impacts before, during, and after land-use change occurs and by developing alternative uses and management strategies, when possible (Dale et al. 1998; Dale et al. 2005B). Management plans may focus on the potential for managing (1) the system prior to the change, (2) the change itself, (3) the system immediately after the change, or (4) the recovery process

Managing initial ecological conditions

Where ecological systems are intact and in a condition similar to their original status, land-management and policy decisions can be designed to enhance resilience (i.e., the ability to rebound after a change) or resistance (i.e., the ability to endure) (Dale et al. 2005B). For example, protecting key areas can reduce ecological vulnerability. Reserve areas should be designed to be large enough to protect habitats, species, and the environmental conditions required to support them and configured to withstand future changes within a region. Typically, the optimal size of protected areas depends on characteristics of both the site and the targeted species (e.g., Hansen and Rotella 2001; Offerman et al. 1995). Forman (1995) argued that the first land-management decisions should be based on location of water and biodiversity concerns, for these are the most susceptible features. He suggests that choices of where people live and grow their food should be secondary. Another way to enhance resilience and resistance of ecological conditions in the face of impending change is to maintain or establish species able to tolerate the changed conditions. For example, salt-tolerant species are often planted in coastal areas and should probably be planted further inland in anticipation of sea-level rise.

Maintaining initial ecological conditions is probably the most cost-effective way to protect environmental conditions but is not always possible or realistic. Reclamation or restoration is costly and difficult to implement successfully, so adopting a proactive and broad-scale perspective on land use and management may be the most effective approach (Robertson et al. 2004). For example, integrated pest management (IPM) is a proactive practice that reduces pesticide use by a four-step approach that (1) sets action thresholds, (2) monitors and identifies pests, (3) prevents pests from becoming a threat, (4) controls pests with pesticides when necessary (and then using less risky chemicals first), and (5) treats only affected areas.

Managing the changes to the land

Changes to the land can be managed in several ways so that they are not so deleterious to ecological conditions (Dale et al. 2005B). By careful site selection and design, strategies can be developed to take advantage of natural features while reducing the chance of adverse impacts. For example, zoning regulations specify the location of land uses; although they typically focus only on making adjacent land uses compatible with socioeconomic goals. The extent to which land use or management is detrimental can vary greatly. For certain land uses, locations that support rare species, have soils and bedrock through which water readily percolates, or are directly connected to groundwater are susceptible to ecological damage. One way to reduce overall impacts of a new land use is to create sacrifice areas where concentrated and intense land uses occur and can be contained so that other areas can be spared. For example, Smart Growth promotes dense residential development, which can allow natural areas to be left undisturbed (ICMA 2007). Another strategy is to adopt designs and regulations that diminish water runoff, atmospheric emissions, and loud noises that result from land-use activities. Land-use practices can be implemented so that deleterious effects are reduced in size, impacts are less likely to occur, or the size or longevity of their legacies are reduced. Technological advancements provide a clear opportunity for improving environmental effects of land use and management. For example, precision agriculture offers ways to place the appropriate amount of fertilizer in a specific location to enhance yield while reducing water-quality impacts.

Managing the ecological processes and structure after the changes

In situations where land use and management have degraded ecological conditions, coping strategies should be developed to promote ecological restoration and mitigate further harmful impacts (Dale et al. 2005B). However, because changes to the land typically are intense, cumulative, and persistent, restoration to the original ecological state is often not possible or will require both a long time and high investment. Land managers need to recognize that a return to original conditions is often not an option. Mitigation and restoration strategies need to be derived from combined efforts of the scientific and decision-making communities. Modifying an ecological system requires a high level of cooperation and agreement among landowners and managers. The few examples of such cooperation [e.g., the Applegate Partnership in Oregon and the Malpai Borderlands Group in southern Arizona (McDonald 1995)] benefit from a firm understanding of collaboration development and building (Wondolleck and Yaffee 2000).

Ecological understanding should be based on sound ecological principles for land use and management (Dale et al. 2000). Coping with changes to the land requires recognizing that human activities are a part of the landscape, and management practices should build on historical changes in the area (Hunter 1993, Hessburg et al. 1999, Landres et al. 1999). The growing literature on desired future conditions recommends setting a more achievable goal than trying to reestablish historical conditions (e.g., Gonzalez 1996, Liu et al. 2000, Druckenbrod et al. 2007). Attainment of desired future conditions can be assessed by a suite of ecological metrics representing key features of the environment (Dale and Beyeler 2001). For example, habitat distribution after management can be compared to that expected under natural-disturbance regimes (e.g., Hunter 1993, Landres et al. 1999). Alternatively, one could make structural changes in the ecological system to enhance function, artificially speed up the rate of succession, or even change the recovery path to an alternative stable state (Leopold 1948, Ludwig et al. 1997, Whisenant 1999). For example, placing trees and debris in recovering streams and lakes can quickly create habitats for a variety of aquatic organisms (Bouget and

Duelli 2004). Sometimes, economic or regulatory incentives are often needed to encourage land managers to implement management practices that promote ecological restoration and are in tune with the environment.

Conclusions

Recent trends in decision making include adopting a more complex view of the world, dealing with increasing environmental pressures, exercising a higher awareness of environmental pressures, engaging more educated and actively involved stakeholders, and employing a higher degree of networking (e.g., through globalization of economies and in the information gathering by stakeholders). In the future, resource management will need to address the full scope of a problem, explore diverse approaches, use long-term vision to direct research and management, explore alternative futures in a gaming mode, and foster extensive communication between scientists and decision makers, even though scientists and decision makers have different goals, perspectives, and techniques.

Integrating research results with decision making enhances understanding of the underlying processes and of the implications of management. Therefore, scientific results must be *both* translated to be meaningful for particular conditions *and* extrapolated beyond a specific study. Furthermore, researchers and key decision makers must engage in active collaboration, focus on the appropriate scales of resolution, include all relevant disciplines and expertise, develop a “living” strategic plan of action, transfer information and technology, and clearly recognize the uncertainties.

Land-use science can inform and enhance land-use planning and management through the application of basic ecological principles and by considering the effects of changing land conditions at several scales. It calls specific attention to four pathways by which land-use and -management practices can affect ecological processes: demography and diversity, land-cover juxtaposition, disturbance regimes, and biogeochemical cycles. It also points out that maintaining initial ecological conditions is probably the most cost-effective way to protect environmental conditions because reclamation or restoration is so costly and difficult to implement successfully.

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