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Evaluating landscape health: integrating societal goals and biophysical process

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Evaluating landscape change requires the integration of the social and natural sciences. The social sciences contribute to articulating societal values that govern landscape change, while the natural sciences contribute to understanding the biophysical processes that are influenced by human activity and result in ecological change. Building upon Aldo Leopold's criteria for landscape health, the roles of societal values and biophysical processes in shaping the landscape are explored. A framework is developed for indicators of landscape health and integrity. Indicators of integrity are useful in measuring biological condition relative to the condition in landscapes largely unaffected by human activity, while indicators of health are useful in evaluating changes in highly modified landscapes.

Integrating societal goals and biophysical processes requires identification of ecological services to be sustained within a given landscape. It also requires the proper choice of temporal and spatial scales. Societal values are based upon inter-generational concerns at regional scales (e.g. soil and ground water quality). Assessing the health and integrity of the environment at the landscape scale over a period of decades best integrates societal values with underlying biophysical processes.

These principles are illustrated in two contrasting case studies: (1) the South Platte River study demonstrates the role of complex biophysical processes acting at a distance; and (2) the Kissimmee River study illustrates the critical importance of social, cultural and economic concerns in the design of remedial action plans. In both studies, however, interactions between the social and the biophysical governed the landscape outcomes. The legacy of evolution and the legacy of culture requires integration for the purpose of effectively coping with environmental change.

Keywords: landscape health, biotic integrity, societal values, indicators, ecological services.

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Introduction

Evaluating changing landscapes calls for an integration of two very different approaches to science—the social and the natural (Turner and Gardner, 1991; Healey 1996). The two endeavours have traditionally been at odds with each other; one addressing the human condition apart from the state of the natural world; the other addressing the state of nature, apart from the human condition. The position that humans are 'part of' and not 'apart from' nature, necessitates the integration of the human-centred and the natural-centred perspectives (Bormann, 1996).

Historically, landscape transformations appear to have been dominated by natural forces, although the effects of human actions were not always negligible. From the extinction of many large mammals worldwide, to the transformation of Cypress forests in the Middle East, humans have had a major influence upon the biota where they live (Diamond, 1997). The combined impact of population, technological change and economic development has greatly increased the magnitude of human impacts on the biosphere. Nearly every accessible landscape has become degraded to some degree (Tolba *et al.*, 1992; Vitousek *et al.*, 1997). Transformations range from altering the physical and chemical environment of life (climate change, soil depletion), to degradation of non-human living systems (over-harvesting of forest and fish resources, habitat destruction, extinction

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of species), to dysfunction in human systems (environmental injustice, social disintegration) (Karr and Chu, 1995).

This rapid and pervasive transformation of the landscape, appears to conflict with societal goals of ecologically sustainable development (World Commission on Environment and Development (WCED, 1987). Introducing the concept of health in the evaluation of landscapes brings into focus this conflict and provides a basis for integrating biophysical processes and societal values for achieving long-term sustainability.

Health and integrity

It is proposed that the twin concepts of health and integrity, as defined in this section, are broadly applicable to evaluating landscapes (Woodley *et al.*, 1993; Ferguson, 1994; Rapport, 1995a; Rapport and Regier, 1995; Shear, 1996). However, while these concepts may be compatible goals, e.g. Principle 7 from the 1992 United Nations conference on Environment and Development (UNCED), refers to the obligation of Nation States to 'safeguard the health and integrity of the world's ecosystems' (UNCED), 1992, they are not identical (Karr, 1996). Actions enhancing one, might depreciate the other. It is important to differentiate between these concepts and match specific applications to their use.

Landscapes are healthy when the cycling of energy and nutrients is not impaired, when the key ecological components are preserved e.g. wildlife, soil and microfauna, when the system is resistant and resilient to long-term effects of natural perturbations and when 'the system does not have to be constantly doctored', (Rolston, 1994). Leopold proposed an overriding criterion for landscape health, namely: '…the capacity of the land for self-renewal.' (Leopold, 1968). Recently, operational measures of health have been proposed (Mageau *et al.*, 1995; Soyza *et al.*, 1997), that apply to both aquatic and terrestrial systems at watershed and landscape scales.

The concept of health as applied to ecosystems and landscapes implies 'well-functioning' and the health of the Earth's ecosystems has become a major concern (UNCED, 1992; Arrow *et al.*, 1995; Belsky, 1995). Healthy landscapes (and ecosystems) may be characterized in terms of general properties such as resilience, diversity and productivity (e.g. Mageau *et al.*, 1995; Rapport, 1995a). In healthy landscapes, these properties are retained, despite human-induced transformations which alter the historic biological and biophysical conditions. These fundamental attributes, although they may be difficult to measure, govern the supply of nature's services derived from the landscape (Cairns and Pratt, 1995; Daily, 1997). Karr (1996) emphasizes the importance of sustainability: healthy landscapes should not be degraded in a manner such that future use is compromized (WCED, 1987). For example, soils should be maintained for future use and ground water should not be depleted. Land use should not cause deleterious effects beyond the site through atmospheric contamination or downstream effects of soil erosion or movements of industrial chemicals. In essence, human-altered landscapes must not compromise societal interests on time scales of decades to centuries or more.

Ecosystem services, as distinct from the notion of economic goods and services, refers to any attribute of natural systems that is perceived as beneficial to human society (Cairns and Pratt, 1995). The term is value-laden, for it refers only to those attributes perceived to be of value to humans. Commonly, at the local level this includes the capacity of ecosystems to cycle nutrients, to sequester eroded sediments, to produce food, fibre and fuel wood, etc. At the biospheric level, the combined functioning of ecosystems helps maintain balance in atmospheric chemistry. Which services are valued by society is, of course, largely dependent on the level of environmental literacy. In a highly environmentally literate society most, if not all, ecosystem functions would likely be viewed as beneficial (Cairns and Pratt, 1995).

Ecological integrity takes as its reference point the condition of naturally evolved ecosystems and landscapes in the absence of significant human interventions (Karr, 1996). Integrity is characterized by reference levels in these pristine systems with respect to species composition, biodiversity and functional organization (Angermeier and Karr, 1994). While few pristine landscapes remain, the notion of 'integrity' provides a point of reference, based on historical data, for judging present conditions in comparison to landscapes that have been minimally impacted by modern humans.

Both the concepts of 'health' and 'integrity' serve useful roles in constructing a framework for evaluating landscape condition. In this paper, 'health' is emphasized, for it appears more broadly applicable to highly modified landscapes, and it resonates well with the general public and policy makers (Simpson, 1989). Further, it is somewhat more flexible in its potential applications, being descriptive of both pristine and human-modified landscapes, for a healthy landscape need satisfy only the requirement of providing an acceptable range of ecosystem services. Indicators of ecological integrity can provide a 'yardstick' for assessment purposes, while indicators of landscape health provide a basis for assessing the suitability of the landscape with respect to specific societal goals.

Leopold advanced the general criteria for landscape health more than half a century ago by defining 'land health' as a condition under which 'the land could be humanly occupied without rendering it dysfunctional', (Leopold, 1941). For Leopold, the main consideration was whether or not modifications of landscape brought about by humans compromized essential ecological functions necessary to sustain landscape components and processes. As humans are 'part of', and not 'apart from' the landscape, Leopold argued that the degree to which the landscape satisfies human needs and aspirations enters prominently into an assessment of landscape health.

The role of societal values

Societal values thus play a central role in contributing to and evaluating landscape condition. Firstly, societal values contribute to landscape condition by encouraging or restraining human activity. For example, in communities where the value of forests as lumber is far greater than the value of the forests as habitat for wildlife, one might expect increased deforestation. Secondly, values play a key role in judging the acceptability of landscape conditions. Problems arise when these two aspects of values conflict. For example, in the lower Fraser River drainage basin in western Canada, stresses from human activity, including over-harvesting of fish and timber, waste discharge to water and air and extensive physical restructuring with inadequate protection of the riparian corridor have resulted in poor water quality, substantial depletion of the salmon fishery and reduced biodiversity. Thus, permissive activities, driven largely by short-term economic goals, have resulted in environmental consequences incompatible with achieving long-term societal goals of sustainability.

When one refers to societal values, at least three different meanings may be implied: (1) a set of philosophical, ethical, moral and emotional principles that order a society (e.g. 'traditional values', 'family values'); (2) intrinsic properties associated with particular environments (e.g. 'wetland values') and (3) economic significance (often measured in monetary terms) of a given landscape.

Values, in the sense of (2) and (3) above, are most relevant for assessing landscape health. One problem that arises when attempting to integrate human values into ecosystem management is that values arise from within landscapes and are highly dependent upon landscape character (Norton, 1995). Conservation programmes often ignore this and begin from an altogether different perspective; focusing on biophysical conditions necessary for sustaining wildlife. Seldom is the question raised explicitly; what ought to be sustained for what purpose? These are questions of societal values (Norton, 1995).

Economism and ecocentrism

Philosophies of environmental management appear to cluster around two centres: economism and ecocentrism (Norton, 1995). These centres need not be regarded as polarized, but instead, complimentary. The first centre (economism) attracts positions that emphasize instrumental values to humans derived from natural objects and processes (value, as mentioned in (3), above). Economism is motivated by a focus on maximizing human welfare, largely through commodity extraction. The second centre (ecocentrism) attracts positions that emphasize that all living things and their interactions have intrinsic value (value, as mentioned in (2), above). This suggests that there are human-independent loci of value in nature and that human interests are often overridden by moral obligations to other species and ecological systems.

In the first approach, economism, the analytic task is to reduce all values, no matter how diverse, to a single measure of aggregated human welfare (e.g. gross national product (GNP)). In the second approach, ecocentrism, the task is to recognize centres of intrinsic value as well as the value of the health and integrity of the system as a whole, and to devise policies that protect the most compelling interests and claims of the competing loci of human-independent value. Neither of these concepts alone provides a comprehensive viewpoint from which to understand the whole range of landscape values (Norton, 1995).

Another way of perceiving the role of values is to contrast the views of a landscape as viewed by an ecologist and an economist. The ecologist may describe the landscape in terms of a complex interplay of nutrients, organisms and energy—a purely biophysical description. The economist may describe the same landscape as a natural physical structure that produces a stream of economic goods and services over time. These two visions of landscape seem to lead to very different conceptions of value. However, they are complementary. Societal values reflect short-term needs (i.e. economic benefits) as well as long-term needs (i.e. ecological benefits) (Norton, 1995).

Quirks of geography

The pattern of landscape functions in relation to the distribution of human populations and their need for ecosystem services is a critical factor in determining value assigned to particular landscape features or processes. Quirks of geography serve either to strengthen or weaken the linkages between human economic and social interests and natural processes. From an economic perspective, landscape values depend upon the capacity of the system to ameliorate negative impacts of human activity or support productive aspects. Thus, the same landscape would be valued differently, depending on the presence of humans and the need for specific services.

Consider, for example, a wetland with the capability to remove nitrogen from the surface waters by denitrification. If that wetland is far removed from human activity and as a result waters entering the wetland are nutrient-poor, denitrification potential is of minimal value. The same wetland might be of far greater value as a waterfowl habitat. But place that same wetland in an agricultural region, upstream from an estuary or coastal embayment showing signs of stress from eutrophication, and the particular values ascribed for that same wetland may change dramatically. Now the capacity of this landscape element for nitrate removal is of far greater value and benefit to humans. In both situations, the physical and ecological processes have not changed, but societal values have. Thus, evaluation of landscape condition requires information on both ecosystem services derived from the landscape and human geography.

Establishing societal values

Human values that are experienced in landscapes determine the value system that guides land use. The very definition of a landscape, whether referring to the pattern of local ecosystem or land use types (Forman, 1995) or the expanse of natural scenery seen by the eye in one view, is suffused with human perspective, human scale and human values. Up to this point, some of the considerations determining value attributed to landscapes have been discussed. How these values might be identified in a practical way, in an effort to maintain ecosystem health, has not yet been considered. For any specific landscape, the identification of community values necessarily entails a participatory process in which all community interests are represented, e.g. conservationists, developers, industry, urban, recreation and agriculture. These interest groups would collectively identify the 'services' that are essential for a healthy landscape. There are a variety of mechanisms that might assist this process, e.g. various gaming methods, surveys and facilitated workshops. The critical point is that the values are derived from the community, and are not externally imposed by scientists. This involvement by communities in environmental decision making, as a part of the 'Participatory Rural Appraisal' (PRA) methodology, integrates societal values with ecological processes to achieve sustainable management of healthy landscapes.

The role of biophysical processes

Biophysical processes are, of course, fundamental in shaping the landscape and in determining its capabilities for providing ecosystem services such as: regulation of runoff, sequestering of contaminants, supply of fresh water, maintenance of biodiversity and provision of food, fibre and wood. If 'the earth is running a fever and we are the flu', (Rowe, 1996) then there is a need to understand the connections between human activity and the changing character of the landscape, i.e. the biophysical mechanisms by which human activity alters the landscape.

The interplay between underlying biophysical processes and ecosystem services may be illustrated by using ground-water recharge as a specific example. Ground-water recharge, a critical ecological function, is probably one of the least appreciated ecosystem services, owing to lack of societal awareness of this process. Within healthy riparian ecosystems or in some aquatic-terrestrial interfaces (ecotones) the rate of water movement can be slowed by vegetation, increasing the likelihood of water percolating into ground water. Well-vegetated alluvial flood plains, for example, slow the movement of floodwaters and absorb and hold water during storms which, in turn, recharges local aquifers and reduces downstream flooding.

The direct benefits of this biophysical process are obvious. Local ground-water supplies are a source for drinking and irrigation in many parts of North America. Losses of riparian vegetation and wetlands in the 48 contiguous states (Swift, 1974) have, by reducing ground-water supplies, reduced flood control and drinking water. This may be one of the major reasons for the unusual severity of floods in recent years in the Pacific northwest, the US mid-west and other regions of the USA. Part of the process of evaluating landscape health is to elucidate mechanisms such as this and to relate these findings to achieving societal goals. Thus, while neither biophysical processes nor societal values alone are sufficient to evaluate landscape health, these two components, in relation to each other, provide the framework for health evaluation.

Indicators of landscape condition

Any assessment of landscape condition must recognize the interaction of values and biophysical conditions at local, regional and global scales. The selection of indicators of landscape health depends on these realities. Throughout evolution, human societies have adapted to the regional ecological context. Technological advances by modern societies appear to make humans less dependent on their immediate natural environment, when in fact they make society more dependent on remote environments. In addition, the landscapes of local communities are larger and are increasingly influenced by remote events and decisions.

In selecting indicators of landscape transformations, the capabilities of natural systems to absorb human usage without serious degradation is an important factor. Indicators thus should concentrate on the 'response' (transformed state in response to stress) side rather than the 'stress' (a pressure the system is not adapted to) side (Friend and Rapport, 1991). For example, suburban developments on barrier islands are less likely to be compatible with retaining a healthy landscape than the same development in an upland wooded landscape. This is obvious, owing to the greater fragility of barrier islands compared to upland wooded areas. A well-designed development, in a location that has inherently high resilience to a spectrum of impacts from human activity, can be compatible with the goal of protecting ecological health, even though it would be unrealistic to think that this development activity would have no negative impacts on the biotic integrity of the area. For example, it is probable that species will be lost; soil generation processes would be altered and terrestrial atmospheric balances will be shifted away from reference conditions in a pristine system.

Transformations of the landscape resulting in reduced biodiversity and altered species composition may still be regarded as 'healthy', provided that ecosystem services remain sufficient to accommodate societal goals.

Landscape-level indicators depend upon whether 'health' or 'integrity' is employed as the integrating concept. Employing 'integrity' focuses indicators on naturally evolved elements and processes. Employing 'health' permits substitutions for natural elements (i.e. non-native and domestic species for indigenous ones), provided that these substitutions have not significantly reduced the efficiency of the processes that sustain the system over time nor diminished the flow of ecosystem services satisfying societal values (Daily, 1997).

Indicators of landscape health

Indicators of ecosystem/landscape health relate to three primary aspects: resilience, productivity and organization (Mageau *et al.*, 1995). Indicators may be drawn from biological measures (e.g. biodiversity, representation by native vs. exotic species, size distribution of dominant species), physical measures (hydrological flows, degree of conservation of soil organic matter, biospheric control of water and energy fluxed to the atmosphere) and socio-economic measures (profitability and investment in agriculture, forestry, fisheries). Landscape indicators reflect 'cross-cutting' interactions between ecosystems, either directly through measures of flows of energy, nutrients or hydrology or through the biological conditions of a subsystem that services as a sentinel for conditions of the larger landscape. Characteristic of indicators of landscape are their capacity to integrate over broad temporal and spatial scales. Energy and nutrient flows predominate in the South Platte River (see Case Studies section). Here water quality in the mountain, plains and wetlands ecosystems serves as a cross-cutting indicator of landscape health. Hydrology predominates in the Kissimmee River ecosystem (see Case Studies section), where the headwaters through to the lowlands (Everglades) are affected by water-level control measures. Biological conditions predominate in a third case study (Wichert and Rapport, 1998), in which changes in fish community structure in riparian systems served as an indicator of the health of the agricultural landscape.

Establishing threshold values for landscape indicators is usually an empirical rather than a theoretical task. Experience with landscapes that maintain ecosystem services and provide an environment that fosters economic well-being and human health as well as a degree of ecological integrity is the most appropriate guide to threshold values.

Maintaining management options

The primary objectives of landscape management are to satisfy present societal goals and to ensure the flow of ecosystem goods and services for future generations. For example, if for a given region a current primary societal value is agricultural production, adopting management practices only to the extent required to sustain agricultural production may prove short-sighted. Maximizing production may compromise future ecosystem services, such as a diversity of gene pools and water quality.

Maintaining or enhancing future management options requires that existing practices allow for the possibility of change in response to evolving needs and values. Societal values fluctuate over time in response to population patterns, economic opportunities, ethics and environmental conditions. Over the long term, the landscape should be assessed in terms of its capacity to respond to changing societal needs and values. The best strategy to meet unknown requirements is to maintain a capacity to provide a wide range of ecosystem services as defined by the Brundtland Commission: nation states should 'meet the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987).

However, as the late Kenneth Boulding once quipped, if one could know the future, the future would already be present. Not only is it impossible to anticipate all possible futures, but meeting current needs (e.g. for urbanization) undoubtedly constrains certain futures (e.g. providing wilderness). Given these considerations, management ought to consider a broad range of potential societal needs and goals and then strive to achieve maximum flexibility for future options.

Spatial and temporal scales of valuation

Evaluative decisions about environmental issues are scale dependent. At the landscape scale, values tend to be focused on processes that contribute to the resilience of regional environments. These processes include the sequestering, dispersion and inactivation of toxic substances, conservation and recycling of water, maintenance of soil quality and prevention of erosion and maintenance of regional biodiversity. These concerns reflect intergenerational community interests rather than short-term individual, or very broad-scale global interests. Landscape management decisions ought to be based on long-term (intergenerational) sustainability which employ mechanisms for sustaining major ecological processes within a regional mosaic which run the gamut from heavily managed systems to nearly pristine systems.

Human values are scale dependent

Environmental values may be viewed in a nested context: individuals focusing on local, short-term interests (e.g. economic returns from ecosystem services); communities focusing on longer-term intergenerational interests (e.g. biophysical processes that sustain regional (landscape) health); and nations focusing on global issues, which involve climate change, the ozone layer, atmospheric circulation of contaminants and other properties that act as boundary conditions for regional systems. Norton (1995) suggests that the temporal, spatial and dominant values shift as one moves from human concerns at the individual, to community to global levels. The two case studies (see Case Studies section), both illustrate human concerns operating at the individual horizon (farms and recreational activities) and the community horizon (greenways along river banks and restoration of original river hydrology).

The landscape mosaic presents a further complexity. Within largely urban, suburban and agricultural landscapes, one often finds significantly impaired natural processes and elements such as reduced biodiversity, disruptions to nutrient cycling from pesticide loading and severely disrupted sediment dynamics. On a small scale, these ecosystems cannot be judged as 'healthy' since they are neither self-sustaining, nor do they safeguard the health of adjacent ecosystems. On a large scale, the landscape may, however, support both disturbed and healthy ecosystems as well as undisturbed areas maintained to protect their biological integrity.

Case studies: The South Platte River and the Kissimmee River

To illustrate the roles of biophysical processes and values in evaluating landscape health two case studies are briefly examined: the South Platte River, Colorado, USA (Klein, 1993; Litke, 1996) and the Kissimmee River, Florida, USA (Karr, 1990; Loftin *et al.*, 1990; and Toth, 1993). In both, human activities have transformed regional landscapes. The South Platte River study illustrates the complex biophysical interactions that, even acting at a distance, can substantially change the character of the landscape. In the Kissimmee River study, the focus shifts to the social science side. Effective rehabilitation of this system was blocked until a landscape perspective was adopted that emphasized the importance of societal values, ecosystem services and ecological integrity.

South Platte River basin

In the South Platte River basin, irrigated agriculture, urbanization and industrialization have altered the land surface of the High Plains east of the Rocky Mountains. This, in turn, altered local and regional atmospheric circulation patterns (Pielke and Avissar, 1990; Stohlgren *et al.*, (unpubl.); Baron *et al.*, (unpubl.). Regional circulation fosters transport of moisture, and industrial and agricultural pollutants from the High Plains up into the Rocky Mountains where they impose stress (excessive nitrogen deposition, climate change) on delicate alpine and subalpine ecosystems (Baron *et al.*, 1994).

Exploitation of land and water resources in the South Platte River basin of Colorado benefits thriving urban and agricultural enterprises, but they also impose costs to the health and integrity of the landscape. The South Platte River begins high in the Rocky Mountains, where logging and mining activities prevalent at the turn of the century have since been replaced by recreational use and suburban development (Veblen and Lorenz, 1991). Current threats to ecological integrity in the upper reaches of the South Platte River basin are by-products of human habitation: fire suppression, weedy species invasions and displacement of native species ranges by recreational and suburban development.

The Great Plains, home to two-thirds of Colorado's human population, are heavily used but with little management to protect either integrity or health. Much of the plains in South Platte are now eroded short-grass steppe owing to poor farming practices between 1870 and 1930. Approximately 40% of the lower basin is cropland and intensive livestock-feeding operations that contribute salinity, dissolved solids, nutrients and organic chemicals to rivers, streams and groundwater. Municipal and industrial discharge and urban runoff further degrade water quality for miles downstream of their inputs. The furthest downstream reaches support wetlands and marshes that are critical habitat for migrating waterfowl such as cranes, geese and ducks, but these areas are severely threatened by competing human water use, including municipal water supply and irrigated agriculture (Deneby *et al.*, 1993; Litke, 1996).

Inhabitants are beginning to address integrated management of the South Platte River basin (Klein, 1993). An example of this is the development of greenways and recreation corridors along the river banks to reduce nutrient and soil loss and to provide aesthetic and recreational opportunities (Smith and Hellmund, 1993). A less obvious example of failure of the partition approach in the South Platte region is regional climate change caused by irrigated agriculture. Recent work suggests that atmospheric dynamics show a strong degree of sensitivity to land surface conditions, in particular to terrain variability and biosphere controls on fluxes of water and energy (Avissar and Pielke, 1989; Pielke and Zeng, 1989; Pielke and Avissar, 1990; Pielke *et al.*, 1991). Land surface heterogeneity strongly affects energy and mass exchange between land and atmosphere, and land and hydrosphere through variability of the radiation environment, precipitation and temperature conditions, and soil water drainage (Band *et al.*, 1991).

There is increasing evidence suggesting transport of air pollutants and moisture from the lower part of the basin to the mountains has been aided by increased transpiration from crops and lawns. Simply put, irrigation adds more moisture and energy to the atmosphere. This increases humidity, dampens temperature ranges and increases the potential for convective storm activity (Pielke and Zheng, 1989; Pielke and Avissar, 1990; Chase *et al.*, (unpubl.); Baron *et al.* (unpubl.); Stohlgren *et al.* (unpubl.). Land-use change alone, then, has the potential to affect the regional climate of the South Platte basin. Since climate is a major determinant of ecosystem structure, there are strong implications for maintenance of ecosystem health and integrity.

While gravity moves most materials down from the mountains to the plains, heat flux and turbulent transfer moves air masses up from the plains into mountain valleys. This daily summer phenomenon, perhaps exacerbated by irrigated cropland transpiration, fosters transport of industrial and agricultural pollutants from the plains into the mountain highlands, where these pollutants are a source of stress to the fragile alpine and subalpine ecosystems by excessive nitrogen deposition (Baron *et al.*, 1994; Williams *et al.*, 1996).

This example illustrates the complexities involved in landscape health assessment. Coloradans value their natural environment and both surveys and legislation suggest that they are willing to pay for a high quality environment. It appears feasible to incorporate intergenerational and landscape considerations into management plans, provided results are fairly clear and immediate. When both the geographical distance and the intellectual effort required to understand the consequences of certain societal actions increases, the maintenance of ecological health and integrity becomes much more difficult to achieve.

In this example, human activities in one sector of a landscape have clearly influenced the integrity of another sector, even if that sector is far removed from the actual source of impact. Landscape management thus becomes more complex, requiring not only managers, but also the regional society to weigh the costs of their activities and act accordingly. Further, the value accorded to maintaining the health and integrity of the Rocky Mountain ecosystems must somehow be factored into decisions regarding regional planning of agriculture, transportation, urbanization and industrialization. Addressing questions of remote area health and integrity from this perspective appears essential to achieving long-term landscape health.

The Kissimmee River basin

The Kissimmee River restoration project is an excellent illustration of the use of a biologically-based landscape perspective for environmental management. For most of the twentieth century, humans sought to control, and thus alter, the natural events that shaped and maintained the landscapes of South Florida. Conversion of lands to agriculture and urban areas was tied to the control and management of water. During the past two decades the aesthetic and economic effects of these activities have sparked public outcry. The evolution of societal values and their integration with biophysical, political, institutional and socio-economic realities is stimulating citizens and Government agencies to re-evaluate a century of activities in the South Florida landscape. From the Kissimmee River and its headwater lakes through Lake Okeechobee to the Everglades ecosystem, including Everglades National Park and the important fisheries and recreational areas of Florida Bay, change is in the wind.

Flooding early in the century generated pressure to control the Kissimmee River by channelization, an activity that was authorized in the 1940s, initiated in the 1960s and completed in 1971. Channelization converted 180 km of natural meandering channel into a 90 km canal with a project designed to lower and regulate water levels in the river's headwater lakes, modify discharge characteristics of the river and open land for agriculture (largely grazing and dairy operations). The project created a series of stagnant reservoirs with a central drainage canal (Toth, 1990).

The first indication that something was wrong was when nutrient delivery to downstream Lake Okeechobee increased. Soon, however, focus was on the loss of numerous other natural resource values. At least 12 000 ha of floodplain wetlands were lost; waterfowl use declined by more than 90%, the largemouth bass fishery was reduced, and at least six species of fish were extirpated (Toth, 1993). By 1976 the Florida State Legislature formed a co-ordinating council of state agencies: (1) to use the natural and free energies of the river system; (2) to restore natural seasonal water-level fluctuations; and (3) to restore conditions favourable to increases in abundance of the native biota. That legislation created a clear and explicit mandate and subsequent legislation (e.g. 1981 Save Our Rivers Act; 1987 Surface Water Improvement and Management Act) strengthened the mandate. A clear shift in perception is obvious; rather than seeing the Kissimmee as a river prone to flooding, Floridians began to see the Kissimmee as a landscape that provided multiple values to local, regional and national society.

The restoration discussions were tense as participants debated specific resource management goals, for example, whether to maximize fish vs. waterfowl populations. By 1988, a special symposium (Loftin *et al.*, 1990) helped to focus restoration efforts towards an integrative goal—to restore the integrity of the combined river and floodplain ecosystems (Karr, 1990). The shift to a health/integrity goal—restoring the capability to support and maintain the biological systems associated with natural habitat in the region (Karr and Dudley, 1981)—defused tension as it placed emphasis on restoring the landscape dynamics that sustained fish, birds and other natural resource values. By defining the integrity goal and emphasizing the biological context of resource loss, the focus shifted from restoration of specific taxa or functions to identification of the causal mechanisms that led to the losses. Altered hydrology was the ultimate factor responsible for the loss and the restoration of five critical hydrological criteria were defined by reference to pre-channelization hydrology of the Kissimmee River (Toth, 1993):

- continuous flow with duration and variability characteristics comparable to the pre-channelization system;
- average velocities between 0·3 and $0{\cdot}6\,m^3\,s^{-1}$ when flows are contained in the channel banks;
- a stage-discharge relationship that results in overbank flow when discharges exceed $40–57\,m^3\,s^{-1}$;
- stage recession rates that typically do not exceed 0·3 m per month;
- stage hydrographs that yield floodplain inundation frequencies comparable to pre-channelization hydroperiods, including seasonal and long-term variability patterns.

These hydrologic criteria were coupled with physical guidelines to re-establish the lateral and longitudinal connectivity between the river and its floodplain and the mosaic of pre-channelization habitats that occupied the Kissimmee landscape (Toth and Aumen, 1994). By restoring control of the system to natural hydrological processes a scientifically sound method avoided controversy associated with selection of 'discrete taxonomic components or ecological functions' (Toth and Aumen, 1994). The Kissimmee case study illustrates the important role of integration of management across complex landscapes, including the transitional ecotones between major landscape components (Naiman *et al.*, 1988; Naiman and Décamps, 1990) that buffer the effects of each landscape component on surrounding areas. These transitional environments provide refugia for terrestrial organisms in times of drought; habitat for threatened, rare and endangered species; nesting and breeding areas for both terrestrial and aquatic species; and filtering capacity to remove pollutants from surface runoff before it is delivered to water bodies (Naiman and Décamps, 1990; 1997). Due to the complexity and integrative nature of the integrity goal, the physical criteria, including hydrological elements, which are defined to accomplish biological goals, must be interdependent and mutually reinforcing. All criteria must be met simultaneously. The next step in the process was to evaluate a range of restoration alternatives, from doing nothing, to the insertion of sheet-metal weirs in the canal to divert water to remnant river channels to complete backfilling of the canal. Only the complete backfill met all established hydrological criteria and maintained flood protection to private property as provided by the existing flood control project. A committee to evaluate restoration alternatives suggested that a systematic effort to evaluate the success of the restoration effort was essential. The general design of a 'restoration evaluation programme' was outlined by an interdisciplinary team of scientists (Karr *et al.*, 1991) to integrate taxonomic, habitat, functional, structural and conceptual approaches. Since the advance of the Kissimmee River restoration, similar initiatives were undertaken in the Everglades to the south (Harwell, 1997). The overall effort is clearly the largest restoration programme ever conceived and the early definition of an integrity goal was instrumental in moving the effort forward after nearly 2 decades of unfocused conversation.

The Kissimmee restoration effort was successful because of the leadership of several scientists involved with the project, the board and managers of the South Florida Water Management District, and the concerned citizens and political leaders of the region. Toth and Aumen (1994), in making recommendations for success in implementing integrated environmental restoration and resource enhancement programmes, outlined the need for a thorough evaluation of the social, cultural and economic issues and concerns in the planning process; the importance of establishing continuous lines of communication for educating the public, environmental organizations and support groups; the need for a well-designed ecological evaluation programme; and the implementation of integrated environmental management and restoration according to natural boundaries instead of political or jurisdictional boundaries.

The Kissimmee restoration project illustrates the role that a landscape perspective can play in advancing efforts to protect and restore the integrity and health of natural resources. But projects on this scale require a shift in societal attitude. Rather than emphasize instant gratification with complex engineering design, the slower but more effective progress must be accepted that is derived from allowing natural processes to resume and provide the basis for landscape restoration.

Conclusions and synthesis

Landscape health as a societal goal

The conceptual framework used here for evaluating the condition and sustainability of landscapes is based on the requirements for landscape health and integrity. It is suggested that although these concepts are different, there is broad overlap in applications to evaluation of modified landscapes. The goal of landscape health is more appropriate for the human modified landscape, while the goal of landscape integrity applies more to the undisturbed landscape. All regional landscapes should sustain areas that protect both health and integrity.

The framework identifies indicators of both landscape pattern and process and relates these to questions of scale. The nature of the dual role of societal values and biophysical process in determining the character of the landscape is emphasized. Assessments of landscape health are critically dependent upon identification of societal values and upon the nature of biophysical processes. Both aspects provide criteria for management of human activity in specific regions. Health at the landscape scale is dependent on simultaneously meeting two primary goals: (1) providing ecosystem services undiminished in quantity and quality by human activity; and (2) maintaining future management options so as to accommodate changes in societal values. Both are constrained to a significant degree by biophysical limitations.

Reconciling societal values and biophysical process

How might societal values be reconciled with biophysical processes? The case studies illustrate that the reconciliation is through sustaining ecosystem services in a landscape mosaic. The identification of services such as sustaining crop yields, provision of adequate supplies of good quality drinking water, maintenance of wildlife and biodiversity is dependent on societal values. Achieving these services is dependent on the well-functioning of underlying biophysical processes, such as hydrology, nutrient cycling and energy transfers. The landscape health framework used here focuses on this duality; it integrates both the biophysical processes molding the landscape and the societal values reflecting what people care about.

Compatibility of process and value scales

Frequent reference has been made to the fact that both values and biophysical processes are scale dependent. The landscape scale captures many values that are critical to the community, i.e. are intergenerational in nature, and places a high priority on sustaining these. This is also the appropriate scale for identifying key processes for maintaining ecosystem services. The merger of biophysical systems and community values, at appropriate spatial and temporal scales, serves as the underlying basis for landscape health assessments.

Criteria for landscape health

As moves are made to assess landscape health, what are the key features of ecologically sustainable environments? These features derive from, and must be consistent with, the landscape assessment framework developed above. Landscape health is characterized by:

- the provision of a suite of ecosystem goods and services that satisfy the present (and anticipated future) needs of society;
- the capability for sustaining the flow of ecosystem services without subsidy—or in the case of agriculture and other intensively managed ecosystems, with minimal and non-increasing subsidy, particularly with respect to fossil fuel use;
- the achievement of economic viability and social welfare without negatively impacting the health of neighbouring landscapes and ecosystems. In terms of

societal value, the landscape as a provider of goods and services suggests that the extent of reduction in the provision of these goods and services, might itself be used as one indicator of landscape health (Regier and Baskerville, 1986); and
- the maintenance of management options (Rapport, 1995b). This provision allows a built-in consideration for future generations to chose their own destiny and have the flexibility for managing landscapes for a wide variety of future needs that may not be foreseen today.

Challenges in applying landscape health principles

Past mismanagement was driven by a framework for analysis that failed to reveal the true social costs of achieving narrowly specified goals. Recent experience suggests that corrections to economically and politically motivated actions in favour of environmental stewardship are by-and-large reactive rather than proactive (Hartig and Zarull, 1992). While a number of ecological–economic models and approaches redress conventional limitations of market mechanisms (Gore, 1992; Rose, 1992; Janssen and Rotmans, 1995; Prugh *et al.*, 1995), few have been implemented and even fewer have succeeded in modifying the widespread belief that damage to landscapes can always be effectively dealt with 'after the fact'. Society is not immune to ecological risk; natural systems under stress cannot always be repaired or replaced (Karr, 1995).

The prevailing attitudes, treating ecosystem services as 'free' and largely independent of natural capital, has enhanced material well-being in the present to the cost of the depletion of natural capital and impairment of underlying biophysical and ecological processes (Arrow *et al.*, 1995; Prugh *et al.*, 1995). Maddox and others have argued that this is a rational and not unreasonable approach, given the marvels of new technology (Maddox, 1995). Declining output in extractive resource sectors (e.g. forestry, fisheries, agriculture) has historically been partially offset over the short term through the additional input of energy (subsidy) whether in the form of fertilizer applications, hatchery operations, capital investment in larger vessels, wood-duck boxes or water treatment plants. This is an unsustainable practice. The Kissimmee River restoration project highlights the importance of understanding and restoring biophysical process in order to restore and sustain valued system elements.

Assuming that the economic process is largely independent of natural capital may have been valid historically, when resources were more plentiful and the stresses on natural systems had not yet reached a level where these systems were significantly damaged. Today, the situation is very different (Brown *et al.*, 1989; Tolba *et al.*, 1992). The 'side-effects' of the economic process have degraded many essential services from ecosystems and landscapes. The evolution of frameworks for environmental indicators, developed over the past 2 decades, demonstrates widespread recognition of the side effects (Rapport, 1992).

Such developments provide a sharp contrast to the classical economic model in which human activity is divorced from environmental effects. The conceptual framework proposed here for evaluating landscape health provides a structure whereby indicators of landscape and ecosystem condition are related to both biophysical processes and societal values. Assessments of landscape health will be far more meaningful if indicators are shown to be applicable to both processes and values. It is the intersection of societal values and ecological processes that is the key to motivating positive change for the common good. It is also contended that the greatest impediment to improvement in the environment is not the lack of scientific understanding, but the lack of knowledge and wisdom to move from reactive to proactive interventions (Naiman, 1996).

One of the perplexing challenges in landscape ecology is how to integrate across the mosaic of ecosystems that comprise the landscape and to what end. Those are the questions that are being addressed currently. The notion of landscape health helps to define purpose. Healthy landscapes are those that provide an abundance of ecological services, including biodiversity, which relates both to human well-being and the well-being of other species. They are also characterized by healthy human populations, healthy social structures and where economic activity is an important element, a viable economic base.

Landscape ecology has yet to address adequately one of its major conundrums: what are the cross-cutting indicators by which one can evaluate conditions of the entire mosaic of ecosystems comprising a given landscape? This is far more than a question of proper scale. It is a question of integration, bringing together all of the elements of a landscape, from the natural areas (both terrestrial and aquatic) to the managed and highly settled areas. The health metaphor might suggest a focus on the critical 'organs' of the system. These might be the interfaces between ecosystem components or other critical nodes within the landscape. Indicators of function derived from the interfaces of ecosystem components (i.e. ecotones) are highly relevant, if for no other reason than they, by their very nature, reflect interactions among the component ecosystems. Some interfaces, e.g. wetlands, do much more than that. They can serve as repositories for the effects of physical restructuring throughout the landscape, and they serve as breeding grounds for a diverse fauna that may play key roles in many of the components of the landscape. Monitoring health of the large landscape should, in time, become a question of monitoring critical functions at critical places within the landscape. Here this important issue can only be raised. Its solution will rest on empirical studies which identify and validate sensitive nodes and indicators (Wichert and Rapport, 1998).

It is worth emphasizing that the above arguments must be considered in the dynamic context of complex systems (Kay, 1991; Walters, 1992). The shift from an economic-based paradigm to an ecological/socio/economic paradigm is encapsulated in the form of a 'manifesto' stated below, accepted by participants in a landscape workshop from which this paper derived:

'Before eight to ten thousand years ago, humans could take with little thought for the morrow. Each new technological innovation likely improved our adaptive value. There is also the legacy of culture. Both are the legacy of our evolution. Leaders of the enlightenment period validated the notion that knowledge is adequate to run the world, even in light of the fact that we are billions of times more ignorant than knowledgeable and always will be. The founders of modern science also validated the placement of part over whole. We are now at an historical juncture in which we realize that both the evolutionary and cultural legacy are environmentally ruinous, largely because they narrow both time and space boundaries of consideration. By expanding these boundaries, we can greatly minimize our errors. The merger of ecological and social science is an effective means for providing antidotes to the environmental problems that beset us.'

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References

Angermeier, P. L. and Karr, J. R. (1994). Biological integrity versus biological diversity as policy directives. *Bioscience* **44**, 690–697.

Arrow, K., Bollin, B., Costanza, R. *et al.* (1995). Economic growth, carrying capacity and the environment. *Science* **268**, 520–521.

Avissar, R. and Pielke, R. A. (1989). A parameterization of heterogeneous land surface for atmospheric numerical models and its impact on regional meteorology. *Monthly Weather Review* **117**, 2113–2136.

Band, L. E. (1991). Forest ecosystem processes at the watershed scale: basis for distributed simulation. *Ecological Modelling* **56**, 171–196.

Baron, J. S. (1994). Analysis of nitrogen saturation potential in Rocky Mountain tundra and forest: implications for aquatic systems. *Biogeochemistry* **27**, 61–82.

Baron, J.S., Hartman, M.D., Kittel, T.G.F., Band, L.E., Ojima, D.S. and Lammers, R.B. (1998). Effects of land cover, water redistribution, and temperature on ecosystem processes in the South Platte Basin. *Ecological Applications* (in press).

Belsky, M. H. (1995). Implementing the ecosystem management approach: optimism or fantasy? *Ecosystem Health* **1**, 214–221.

Bormann, F. H. (1996). Ecology: A personal history. *Annual Review of Energy and Environment* **21** 1–29.

Brown, L. R. *et al.* (1989). A world at risk. In *State of the World* (L. R. Brown *et al.*, eds), A Worldwatch Institute report on progress toward a sustainable society. New York: W.W. Norton and Co.

Cairns, J. Jr. and Pratt, J. R. (1995). The relationship between ecosystem health and delivery of ecosystem services. In *Evaluating and Monitoring the Health of Large-Scale Ecosystems* (D.J. Rapport, C. Gaudet and P. Calow, eds), New York: Springer-Verlag.

Chase, T.N., Pielke, R.A., Kittel, T.G.F. and Baron, J.S. Impacts on Rocky Mountain weather and climate due to land use changes in the adjacent Great Plains. *Journal of Geophysical Research* (unpubl.).

Daily, G (ed.) (1997). *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington: Island Press.

Denneby, K.F., Litke, D.W., Tate, C.M. and Heiny, J.S. (1993). South Platte River Basin—Colorado, Nebraska and Wyoming. *Water Resource Bulletin* **29**, 647–683.

Diamond, J.M. (1997). *Guns, Germs and Steel: The Fates of Human Societies.* New York: WW Norton and Co.

Environmental Protection Agency (EPA) (1994). *Evaluating Landscape Health: Identifying Landscape Values and Approaches to Assessment*. EPA sponsored workshop. Portal, Arizona, USA.

Ferguson, B. K. (1994). The concept of landscape health. *Journal of Environmental Management* **40**, 129–137.

Forman, R. T. T. (1995). Some general principles of landscape and regional ecology. *Landscape Ecology* **10**, 133–142.

Friend, A. M. and Rapport, D. J. (1991). Evolution of macro-information systems for sustainable development. *Ecological Economics* **3**, 59–76.

Gore, A. (1992). *Earth in the Balance—Ecology and Human Spirit*. New York: Houghton Mifflin.

Hartig, J.H. and Zarull, M.A. (1992). Towards defining aquatic ecosystem health for the Great Lakes. *Journal of Aquatic Ecosystem Health* **1**, 97–108.

Harwell, M.A. (1997). Ecosystem management of south Florida. *Bioscience* **47**, 499–512.

Healey, M.C. (1996). Paradigms, policies and prognostication about watershed ecosystems and their management. In *Ecology and Management of Streams and Rivers in the Pacific Northwest Coastal Ecoregion* (R.J. Naiman and R.E. Bilby, eds) unpubl. manuscript.

Janssen, M. and Rotmans, J. (1995). Allocation of fossil CO_2 emission rights quantifying cultural perspectives. *Ecological Economics* **13**, 65–79.

Karr, J. R. (1990). Kissimmee River: Restoration of degraded resources. In *Proceedings of the Kissimmee River Restoration Symposium. South Florida Water Management District* (M. K. Loftin, L. A. Toth and J. T. B. Obeysekera, eds), pp. 303–320. FL: West Palm Beach.

Karr, J.R. (1995). Risk assessment: we need more than an ecological veneer. *Human and Ecological Risk Assessment* **1**, 436–447.

Karr, J.R. (1996). Ecological integrity and ecological health are not the same. In *Engineering Within Ecological Constraints,* (Peter C. Schulze, ed.), pp. 97–109. Washington, DC: National Academy Press.

Karr, J. R. and Dudley, D.R. (1981). Ecological perspectives on waterquality goals. *Environmental Management* **5**, 55–68.

Karr, J.R. and Chu, E.W. (1995). Ecological integrity: reclaiming lost connections. In *Perspectives on Ecological Integrity* (L. Westra and J. Lemons, eds), pp. 34–48. The Netherlands: Kluwer Academic Publishers.

Karr, J.R., Stefan, H., Benke, A.C. *et al.* (1991). *Design of a Restoration Evaluation Program.* South Florida Water Management District, West Palm Beach, FL, USA.

Kay, J.J. (1991). A nonequilibrium thermodynamic framework for discussing ecosystem integrity. *Environmental Management* **15**, 483–495.

Klein, K.C. (ed.) (1993). Seeing an integrated approach to watershed management for the South Platte Basin: *Proceedings of the 1993 South Platte Forum* Colorado Water Resources Research Institute Information Series No. 76. Colorado State University, Fort Collins CO, USA.

Leopold, A. (1941). Wilderness as a land laboratory. *Living Wilderness* **6**, 3.

Leopold, A. (1968). [1949] *A Sand County Almanac*. New York: Oxford University Press.

Litke, D.W. (1996). Sources and loads of nutrients in the South Platte River, Colorado and Nebraska. *U.S. Geological Survey Water-Resources Investigations Report 96-4029*. 57pp.

Loftin, M.K., Toth, L.A. and Obeysekera, J.T.B.(eds) (1990). *Proceedings of the Kissimmee River Restoration Symposium. South Florida Water Management District* West Palm Beach, FL, USA.

Maddox, J. (1995). Sustainable development unsustainable. *Nature* **374**, 305.

Mageau, M.T., Costanza, R. and Ulanowicz, R.E. (1995). The development and initial testing of a quantitative assessment of ecosystem health. *Ecosystem Health* **1**, 201–213.

Naiman, R.J. (1996). Water, socity and landscape ecology. *Landscape Ecology* (unpubl.).

Naiman, R.J., Décamps, H., Pastor, J. and Johnson, C.A. (1988). The potential importance of boundaries to fluvial ecosystems. *Journal of the North American Benthological Society* (unpubl.).

Naiman, R.J. and Décamps. (eds) (1990). *The Ecology and Management of Aquatic-Terrestrial*

Ecotones. Carnforth, UK: Parthenon Publishing Co. and Paris: UNESCO.
Naiman, R.J. and Décamps. (1997). The ecology of boundaries. *Annual Review of Ecology and Systematics* (unpubl.).
Norton, B.G. (1995). Ecological integrity and social values: at what scale. *Ecosystem Health* **1**, 228–241.
Pielke, R.A. and Zeng, X. (1989). Influence on severe storm development of irrigated land. *National Weather Digest* **14**, 16–17.
Pielke, R.A. and Avissar, R. (1990). Influence of landscape structure on local and regional climate. *Landscape Ecology* **4**, 133–155.
Pielke, R.A., Cotton, W.R., Walko, R.L. *et al.* (1991). A comprehensive meteorological modelling system—RAMS. *Meteorological and Atmospheric Physics* **49**, 69–91.
Prugh, T., Costanza, R., Cumberland, J.H., Daly, H., Goodland, R. and Norgaard, R.B. (1995). *Natural Capital and Human Economic Survival.* Solomons Island, MD: ISEE Press.
Rapport, D.J. (1992). Evolution of indicators of ecosystem health. In *Ecological Indicators* (D.H. McKenzie, D.E. Hyatt and V.J. McDonald, eds), Elsevier Applied Science **1**, 121–134.
Rapport, D. J. (1995a). Ecosystem health: an emerging integrative science. In *Evaluating and Monitoring the Health of Large-Scale Ecosystems* (D. J. Rapport, C. L. Gaudet and P. Calow, eds), New York: Springer-Verlag.
Rapport, D. J. (1995b). Ecosystem services and management options as blanket indicators of ecosystem health. *Journal of Aquatic Ecosystem Health* **4**, 97–105.
Rapport, D.J. and Regier, H.A. (1995). Disturbance and stress effects on ecological systems. In *Complex Ecology* (Memorial volume in honour of G. VanDyne), (B.C. Patten and S. E. Jorgensen, eds), pp. 397–414. Englewood Cliffs, NJ: Prentice Hall.
Regier, H.A. and Baskerville, G.L. (1986). Sustainable redevelopment of regional ecosystems degraded by exploitive development. In *Sustainable Development of the Biosphere* (W.C. Clark and R.E. Munn, eds), pp. 75–103. London: Cambridge University Press.
Holmes, R. III. (1994). *Conserving Natural Value.* Columbia: Columbia University Press.
Rose, A. (1992). Equity consideration of tradeable carbon emission entitlements. In *Combating Global Warming: Study on a Global System of Tradeable Carbon Emission Entitlements.* New York, NY: UNCTAD.
Rowe, J.S. (1996). Social values and ecosystem health. *Ecosystem Health* **2**, 101–102.
Shear, H. (1996). The development and use of indicators to assess the state of ecosystem health in the Great Lakes. *Ecosystem Health* **2**, 241–258.
Simpson, J.W. (1989). Landscape medicine: a timely treatment. *Journal of Soil and Water Conservation* **5**, 577–579.
Smith, D.S. and Hellmund, P.C. (eds.) (1993). *Ecology of Greenways: Design and Function of Linear Conservation Areas.* 222 pp. Minneapolis, MN: University of Minnesota Press.
Soyza, A., Whitford, W. and Herrick, J. (1997). Sensitivity testing of indicators of ecosystem health. *Ecosystem Health* **1** (in press)
Stohlgren, T.J., Chase, T.N., Pielke, R.A., Kittel, T.G.F. and Baron, J.S. (1998). Evidence that local land use practices influence regional climate and vegetation patterns in adjacent natural areas. *Global Change Biology* (in press).
Swift, B.L. (1974). Status of riparian ecosystems in the United States. *Water Resource Bulletin* **20**, 223–228.
Tolba, M.K., El-Kholy, O.A., El-Hinnawi, E., Holdgate, M.W., McMichael, D.F. and Munn, R.E. (1992). *The World Environment, 1972–92.* London: Chapman & Hall.
Toth, L.A. (1990). An ecosystem approach to Kissimmee River restoration. In *Proceedings of the Kissimmee River Restoration Symposium. South Florida Water Management District* (M.K. Loftin, L.A. Toth, and J.T.B. Obeysekera, eds), pp. 125–133. Florida: West Palm Beach.
Toth, L. A. (1993). The ecological basis of the Kissimmee River restoration plan. *Florida Scientist* **56** 25–51.
Turner, M.G. and Gardner, R.H. (eds.) (1991). *Quantitative Methods in Landscape Ecology. The Analysis and Interpretation of Landscape Heterogeneity.* New York: Springer-Verlag.
Toth, L.A. and Aumen, N.G. (1994). Integration of multiple uses in environmental restoration and resource enhancement projects in Southcentral Florida. In *Implementing Integrated Environmental Management* (J. Cairns, Jr., T. V. Crawford and H. Salwasser, eds), pp 61–78. Blacksburg, VA: Virginia Polytechnic Institute and State University.
United Nations Conference on Environment and Development (UNCED) (1992). *The Earth Summit: the United Nations Conference on Environment and Development* (S. Johnson, ed.), London: Graham and Troutman/Martinus Nijhoff.
Vitousek, P. M., Mooney, H. A., Lubchenco, J. and Milillo, J. M. (1997). Human Domination of Earth's Ecosystems. *Science* **277**, 494–499.
Veblen, T.T. and Lorenz, D.C. (1991). *The Colorado Front Range: a Century of Ecological Change.* 186 pp. Salt Lake City: University of Utah Press.
Walters, C.J. (1992). *Adaptive Management of Renewable Resources.* New York: MacMillan.
Wichert, G.A. and Rapport, D.J. (1998). Fish community structure as a measure of degradation and rehabilitation of Riparian Systems in an Agricultural Basin. *Environmental Management* **22(3)**, 425–443.
Williams, M.W., Baron, J.S., Caine, N., Sommerfeld, R. and Sanford, R. (1996). Nitrogen saturation in the Rocky Mountains. *Environmental Science of Technology* **30**, 640–646.
Woodley, S.J., Francis, G. and Kay, J. (eds) (1993). *Ecological Integrity and the Management of Ecosystems.* Ann Arbor, Michigan: Lewis.
WCED (World Commission on Environment and Development) (1987). *Our Common Future.* Oxford, UK: Oxford University Press.