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A Planning and Decision-Making Framework for Ecological Restoration

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ABSTRACT / A broad and objective perspective of ecological and socioeconomic knowledge is required to underlie a scientific approach to the problems of terrestrial restoration ecology. Uncertainty associated with limited scientific knowledge highlights the crucial importance of the interaction between science and policy in weighing ecological restoration alternatives in relation to other management options. In this paper, we provide a pragmatic definition for restoration ecology that is suitable for extensive terrestrial applications and present a decision framework to help organize and clarify different phases of the decision process as it is related to ecological restoration. We argue that restoration planning should include a wider spectrum of participants and decisions than have traditionally been employed.

Ecological restoration is considered by many to be the definitive test for the science of ecology (Bradshaw 1987, Ewel 1987, Cairns 1989, Lubchenco and others 1991, Mitsch 1993, 1994). Restoration definitions, standards, and techniques have been evolving for many decades, and a variety of definitions have been offered for the term "restoration". Early restoration efforts by the Civilian Conservation Corps concentrated on reclaiming lands by converting them from a disturbed state (e.g., logged or mined) to a restored state based on historical vegetation (Berger 1990). Selection of historical condition as a restoration end point was apparently based on a notion that was influential in ecology at the time: the balance of nature. The balance of nature, or equilibrium concept, implicitly assumes that, in the absence of disturbance, biota tend toward a single persistent equilibrium with climate, site, and other biota—the climax condition (Clements 1916).

Many current definitions of restoration also include or imply a return to some historical state as a goal (Table 1). Currently, however, ecological theory recognizes disturbance-induced discontinuous and irreversible transitions, nonequilibrial communities, and stochastic effects in succession (Westoby and others 1989, Overpeck and others 1990, Robertson and others 1990, Harmon and others 1990, Clark 1990, Wyant and others 1991). That is to say, an equilibrial state does not occur in nature and the selection of a specific historical condition is not necessarily desirable or even an achievable goal for ecological restoration. That scientific fact notwithstanding, politically savvy nongovernmental organizations (NGOs) dedicate themselves to promoting restoration activities. In today's political arena, public input is not only desirable, it is frequently mandated by law. Consequently, alternative definitions of restoration ecology, its scope and objectives have evolved over time.

Most of the definitions presented in Table 1 recognize a broader array of factors that should be considered when establishing goals for a restoration attempt. We have attempted to reduce and organize these factors and in the process have developed the following operational definition: "Ecological restoration includes: (1) the identification of ecologically and socially desirable ecosystem values, goods, and services, as determined through a number of scientific and public-input mechanisms; (2) identification of the functional and structural elements essential to a self-sustaining system that will

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Table 1. A sample of definitions of ecological restoration and related terms

Self-sustaining system based on natural reproduction, succession; mimicking a presumed successional stage had the system continued with normal ecological processes; restoration of ecosystem services, either functional or structural, not particular species; removing an annoyance, unacceptable odors, aesthetically displeasing visual situations.	Cairns, 1990
Returned from a disturbed or totally altered condition to a previously existing natural, or altered condition. Restoration refers to the return to a pre-existing condition. . . .	Lewis 1990
The reestablishment of predisturbance functions and related physical, chemical and biological characteristics. . . . The holistic nature of restoration is emphasized.	National Research Council 1992
Process of intentionally altering a site to establish a defined indigenous historic ecosystem.	Aronson and others 1993
General aim is to accelerate reestablishment of balanced plant communities.	Louda 1988
Implies maintenance management over the long-term to ensure stability, integrity, and natural beauty.	Guinon and Allen 1990
As its ultimate goal, perhaps, the achieving of a status something very close to the ecosystem's original conditions.	Hamilton 1990
As reclamation: deliberate attempt to return a damaged ecosystem to some kind of productive use or socially acceptable condition short of restoration.	Jordan and others 1988

provide those values; and finally, (3) facilitation of ecosystem recovery to a self-sustaining state by manipulation of the physical, biological, chemical, and even social or cultural elements of the system." Under this definition a restored ecosystem will not necessarily have the same dominant species, species diversity, production rates, or nutrient cycling rates as a similar undisturbed site; however, essential functional roles will be reestablished so that the restored system is self-sustaining. We suggest that the purpose of ecological restoration is to provide society with the many sustainable benefits produced by a restored ecosystem more quickly than would be possible under a natural recovery process.

Why Is Ecological Restoration Needed?

The critical need for ecological restoration in support of sustainable utilization of the biosphere is one of the key elements in the Ecological Society of America's Sustainable Biosphere Initiative (Lubchenco and others 1991). Natural goods and services are derived from the structure, function, diversity, and dynamics of ecosystems. Goods are usually tangible products, such as timber or fodder, whereas services are often derived from ecosystem processes that are less readily visible and whose benefits are, therefore, nonmarket, less tangible, more difficult to measure, and more likely to be overlooked (Table 2). However, trade-offs among various goods and services are necessary to ensure human welfare. For example, the pastoralists of the mountains in Azad Jammu Kashmir, Pakistan, depend on grazing systems for subsistence. By exploiting lower elevation grasslands and woodlands of the Pothwar Plateau in wintertime, pastoralists are able to keep large, mixed herds. However, this subsistence system requires a variety of disturbances that have direct and indirect effects on grasslands and woodlands that conflict with the needs and values of sedentary agriculturalists of the plateau (Wyant, personal observation). Similarly, in the

Table 2. Examples of terrestrial ecosystem goods and services

Goods
Human food
Live animals (nonfood)
Animal materials (hides, feathers, etc.)
Livestock forage
Water (quality/quantity)
Fuels (biomass)
Plant materials (fertilizers, medicinals, fiber, etc.)
Services
Pollination
Wildlife/endangered species habitat
Migratory corridor
Disease and pest control/protection
Genetic diversity
Climate modification (micro, macro)
Biogeochemical cycling (nutrients, carbon sequestration)
Contaminant decomposition, transport, dilution and storage
Soil generation
Erosion control and sediment trapping
Flood control
Recreation
Scientific research
Heritage value (historical, cultural, uniqueness)

United States, oil field development in Arctic Alaska provides a substantial energy resource. This economic development, in turn, requires a variety of disturbances that have direct and indirect effects on tundra habitat values (Wyant and Knapp 1992).

As the human population grows, it is unlikely that economic activities that produce radical alteration of the natural resource base will cease, and a full range of resource management alternatives will be necessary to meet societal demands. However, given a finite resource base, sustainable production of the goods and services afforded by all ecosystems requires strengthened capabilities to assess and recover the environmental performance of anthropogenicly disrupted ecosystems (Lubchenco and others 1991, Mitsch 1993, 1994).

In the United States, the social desire for ecological restoration has been delineated in nearly 50 federal laws that contain provisions mandating mitigation, rehabilitation, enhancement, or restoration of natural systems (Tripp and Herz 1988). Ecological restoration has also become a current focus of international development. For example, the US Agency for International Development together with the government of El Salvador recently announced a major environmental rehabilitation program. The project is designed to rebuild the viability of the natural resource base in order to support local communities as well as the national economy that had been disrupted by more than a decade of civil strife. Ecological restoration and reclaimation have also been the focus and goal of the Wulan-Adou research station in Inner Mongolia, People's Republic in China, where biologists and economists are attempting to reclaim desertified lands following unsuccessful agriculture settlement (Wyant, personal observation).

The importance of ecological restoration is evident in the spectrum of social, scientific, and legislative mandates to recover sustainable production of the natural goods and services from ecological systems. However, deciding among the myriad choices of restoration goals remains problematic. For example, every stakeholder (i.e., interest group) might insist that the ecosystem be restored to serve their particular interests. Weighing alternatives and ultimately choosing among trade-offs is fundamental to the process of goal-setting for ecological restoration in a pluralistic society.

A Decision Framework

A decision framework is not a theory in that it does not explain, nor is it a model because it does not provide a prediction. A decision framework simply organizes information. For example, the decision framework outlined in Figure 1 can be used to organize the fundamental information used (either explicitly or implicitly) when alternative goals are evaluated for a restoration project. It might also serve to identify differences among stakeholders' values. The decision framework can be used to understand where decision making may be information-limited and suggest priorities for research and stakeholder involvement. For example, identifying where explicit information cannot be substituted for implicit assumptions in the decision framework will highlight specific research needs.

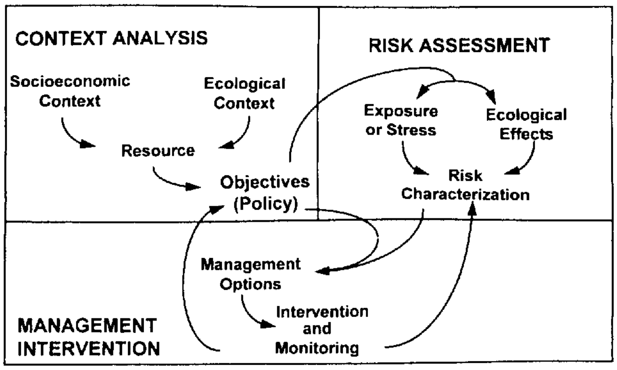

Figure 1. A decision framework for selection among choices in ecological restoration.

When faced with the prospect of initiating an ecological restoration program, the limits of our scientific knowledge and the associated uncertainties highlight the crucial importance of the interaction between science and policy (e.g., Wyant and Knapp 1992). How should ecological restoration alternatives be weighed in relation to other management options? One approach is to examine the decisions that might be needed when choosing a specific restoration approach (Wyant and Knapp 1992). In general, questions arise as to: (1) the goals or desirable endpoints of restoration, (2) the cumulative ecological impact of anthropogenic stresses and how this determines the need for restoration, (3) the best methods and technologies to employ in restoration activities, and (4) how the success or failure of restoration attempts will be judged.

The decision process should assess stakeholders' opinions about desired outcomes of the restoration program. Although the fundamental premise of sustainability must underlie any restoration effort, there may be wide disagreement about the desired physical appearance and condition of the site, as well as about the interests it should serve and the goods and services it should ultimately produce.

Context Analysis

The context analysis portion of Figure 1 represents the process of setting goals for the restoration project. We believe that both the ecological and socioeconomic contexts in which the ecosystem restoration will occur must be considered in setting restoration project goals. First, the goals of restoration efforts must have meaning to society (i.e., include the various stakeholder interests). It is important to note here that the recognition of an ecosystem good or service is dependent on the social and cultural context. For example, agriculturalists on the Pothwar Plateau of Pakistan use wheat straw and other crop residues as animal fodder, while in the Willamette Valley of Oregon, straw residues are considered a waste product and are burned. Therefore, we must provide formal expressions of socially and culturally desired ecological characteristics that are based on the local context and that, if found to be substantially affected, will indicate an unsatisfied need and suggest the need and goals for additional or alternative restoration actions.

A context analysis strategy of setting goals is fast becoming an integral mode for planning international development activities. Technical assistance agencies and international financing institutions (e.g., World Bank, Interamerican Development Bank) are now mandated to involve communities in the planning of development projects, as well as in prioritizing investments. For example, the Organization of American States used a similar approach to context analysis in planning the La Amistad National Park and its surrounding lands between Panama and Costa Rica. Other examples include the work of The Nature Conservancy and the UN Environment Programme, which have recently undertaken a process of community involvement and comanagement in the initial planning stages of a buffer zone and conservation corridor between two Jamaican protected areas (Chambers 1993).

Analysis of the ecological context includes consideration of limiting factors, such as climate, geology, natural disturbance regimes, etc., which determine limits to ecosystem composition, structure, and function. These factors also constrain our expectations for natural goods and services that might be produced from the restored ecosystem because these possibilities are governed by the ecological context of the restoration project.

Analysis of the social context includes traditional cost-benefit studies, consideration of community goals, and development of alternative visions about the desired outcomes of restoration efforts. Within almost any community there exist a multitude of needs, interests, and ideas about what constitutes value in nature and natural systems. Restoration efforts must begin with an attempt to understand and, if possible, accommodate these differences before the restoration effort is designed and put into place. For example, a research program in Tikal National Park, Guatemala, will assess both the ecological and social values of bird and mammal species as the starting point for designing programs to monitor and mitigate impacts on selected species (Ham, personal observation). In this research, ecological values include structural and functional considerations, whereas social values comprise subsistence uses, religion, and economic and aesthetic considerations.

As Chambers and Ham (1995) have argued, a potentially problematic variable in social context analysis is the amount of knowledge that stakeholders have about the land, the natural resource base, and the ecological processes that give rise to it. To some degree, the ability of local people to participate in an informed way in ecological restoration goal setting may depend on their access to knowledge about the workings of the ecosystem in question. Understanding what the ecosystem is capable and incapable of producing sustainably, and being able to judge the likelihood and acceptability of different types of impacts, are key advantages to sound ecological decision making. For these reasons, analysis of the social context should usually include an assessment of stakeholders' knowledge levels about the issues at hand, as well as implementation of appropriate community education efforts aimed at giving local people information and ecological awareness that will help them in offering informed input as restoration goals are set and as desired outcomes are envisioned.

A recent study assessing methodological frameworks for project evaluation concluded that public goods have various characteristics that they possess to differing degrees depending on the user group (UNEP 1993). Conceptually, the ecosystem is the level of organization at which physical, chemical, and biological attributes are integrated, while the state of landscape characteristics is often taken to be diagnostic for evaluating land with respect to a given use and management regime (Shanholtz and others 1988, Burrough 1989). Certainly, ecosystem science and landscape ecology should be an essential part of our context analysis and risk assessment. Yet, little effort has been expended to incorporate these sciences into historic restoration planning.

What can ecosystem science contribute to restoration? The complex and dynamic nature of ecosystems are properties which, if understood, afford choices for restoration purposes. By developing and applying a consistent conceptual model of ecosystem species composition and physical structure and function, we enhance our ability to ask the proper questions in the context analysis. An ecosystem model can be used to anticipate restoration effects on conditions that govern the production of specific ecological goods and services. When this conceptual structure is combined with site-specific knowledge, it will then be feasible to prescribe restoration actions targeted to a specific suite of socially desired ecosystem goods and services based on not only what a given ecosystem is capable of producing sustainably, but on what affected human populations desire and need within those biological parameters. Minimally, our conceptual model of the ecological context must account for: (1) physical environment, (2) elemental cycling, and (3) community processes that include competition, biotic diversity, and succession (Lubchenco and others 1991). At present, the information available on these interrelationships and on the efficacy of long-term methods to restore ecosystems to acceptable structural and functional levels varies greatly with the type of ecosystem.

Recent studies have demonstrated that ecological systems are open. That is to say, their properties are determined in part by what happens within them, but also by processes that operate in the larger system within which they are imbedded (Allen and others 1984, Brown and Roughgarden 1990). Employing ecosystem science in restoration planning and goal setting activities will require integration of knowledge of the site and the landscape within which the restoration will occur.

We see the range of goals as being determined by a hierarchical process in which management goals for the region and its component landscapes are established prior to the establishment of site-specific goals (e.g., What do we want the landscapes to be like after restoration has been completed?). These higher-order management goals might include, for example, statements of what mix and spatial arrangement of habitats is deemed desirable, which ecological characteristics are considered most valuable, etc. Examining the larger-scale landscape and regional context is a mechanism that limits the realm of choices for site-level interventions to those that are both ecologically possible, given local constraints, and socially desirable, given local values. The socioeconomic context will help determine which particular mix of the possible natural goods and services is most desirable.

Landscape ecology emphasizes the ecological effects of spatial patterns in large areas. Like restoration ecology, it is a young science; therefore, the role that it may play in the context of restoration will initially require research. However, we understand that because basic properties of the land and water vary in both space and time, any sensible system of resource assessment and planning must have information about landscape characteristics and the spatial distribution of those characteristics, and how temporal change in land quality values may occur. Temporal changes in landscape characteristics will usually be accompanied by changes in spatial patterns of land and water characteristics. The complex attributes of landscapes, like the complexities of ecosystems, if viewed as assets can allow a degree of flexibility in goal setting for ecological restoration.

Risk Assessment

After the range of ecological and social goals has been identified, it is necessary to establish priorities among the competing possibilities. One mechanism is to estimate the potential for loss of critical resources from the landscape by human-caused disturbances, such as land form conversion or the introduction of pollutants. Higher priority might be given to restoration efforts that recover the sustainable production of desired goods and services that are at greatest risk from anthropogenic stresses. Characterizing risk includes a joint analysis of the intensity of anthropogenic stresses and the likelihood that those stresses will threaten critical ecological resources.

A challenge in assessing risk to ecological resources is the fact that human-caused disturbances frequently are linked through complex indirect pathways to the affected resource. In addition, a series of natural disturbances and normal cyclic instabilities also effect ecological resources. Two fundamental questions must be resolved: (1) determining the normal instability in ecological resources that arises from natural disturbances (e.g., fire, weather, and disease) and other temporally dynamic processes (e.g., succession and eutrophication), and (2) judging the human-caused reduction, loss, or enhancement of ecological resources against this background of natural variation.

A detailed examination of the literature related to environmental risk assessment is beyond the scope of our discussion. Our emphasis here is to highlight the necessity for inclusion, or at least consideration, of risk analysis in terrestrial restoration decision-making processes. Some examples of formal risk assessment techniques are presented in Table 3.

Assessing system-wide risk associated with myriad natural disturbances and human actions cannot be very precise. To provide the best possible level of precision in system-wide risk assessment, we suggest an approach that strategically links site-level process studies with landscape-level risk assessment and integrates assessment natural and anthropogenic disturbances as they drive biological cycles.

Context analysis and risk assessment are two essential steps in our strategy for setting priorities among the many possible choices for ecological restoration. These

Table 3 Formal analyses that may be included in failure/risk assessment

Preliminary hazard analysis	Identifies hazards as early as possible in the restoration planning process (a hazard is a condition that can cause a failure, if other events also occur).
Event-tree analysis	Begins with the identification of some untoward event such as drought or a wild fire that affects the restored ecosystem and then imagines the consequences that could result.
Fault-tree analysis	Starts backwards, imagining a specific system failure (e.g., decline in net ecosystem productivity or an imbalance in the ratios of predators to prey) and attempts to identify all of the ways that the failure might have come about.
Failure modes and effects analysis	Attempts to identify every possible way each component (or each interface among components) could fail (i.e., each failure mode). It then goes on to consider the effect each failure mode will have on the system.
Human reliability analysis	Tries to identify how people interacting with the restored ecosystem might cause it to fail. Reliability is the probability that the system or subsystem will perform its function for a specific period.

procedures help us to formally identify ecological restoration efforts that are ecologically possible and will reduce the risk of the loss of socially desirable goods and services. Once goals and priorities are established, it remains to identify and select appropriate methods and techniques for attaining these ends.

Management Intervention

Selection of a specific intervention includes choices from the various ecological engineering techniques available for altering site conditions, execution of those techniques intended to establish desired ecological conditions, and evaluation of the success of a particular effort. Historically, development of restoration methods has addressed the need to establish persistent vegetation on disturbed sites to control erosion or nonpoint source water quality and to mitigate aesthetic impacts. However, because our concept of restoration is oriented toward recovery of the landscape-scale functions and values of ecosystems, we call for the development of new approaches to site-scale ecological engineering. This entails identifying ecological engineering methods that will initiate processes leading to establishment of naturally functioning and self-sustaining ecosystems that are integral parts of the landscape.

Because of the variety of disturbances and the sites at which they occur, the field of restoration ecology demands the development of an array of physical, chemical, and biological techniques that can be used independently, and in concert, to achieve the desired outcomes from different initial conditions. We suggest that the most pragmatic means of hastening recovery of ecological resources will be to identify engineering intervention techniques that mimic natural processes that: (1) establish the contextually appropriate physical stability of the site (which may include a regime of physical instability as in fluvial systems), (2) initiate soil development, and (3) facilitate invasion by native vegetation. Reestablishing an appropriate level of physical stability entails implementing measures to avoid erosion or siltation rates that are dissimilar to the normal rates observed in the surrounding landscape. Once measures to promote physical stability have been implemented, efforts to reestablish native vegetation will likely be called for. This process includes at least two major components: (1) establishing early successional species of plants and soil organisms to begin nutrient cycling, and (2) accelerating the rate of accumulation of ecosystem reserves (e.g., pool of available plant species, below-ground biomass of plant roots and soil organisms, and carbon reserves). These two steps are essential to reestablishing the ecosystem's ability to withstand disturbance or periodic fluctuations in the physical environment. In addition, it may be desirable to enhance nutrient retention and nutrient cycling by stimulating growth of tolerant native or adapted bacterial, fungal, or algal microflora. It also may be desirable to develop innovative techniques for manipulating small-scale thermal and hydrologic regimes to enhance seed production of native vascular plants. Through the prospects of application of native or bioengineered mycorrhizae and soil organisms, other innovative approaches can be explored.

Monitoring is the feedback loop providing a mechanism through which the combined effectiveness of the risk assessment, context analysis, and management intervention is weighed. Until the field of restoration ecology develops more robust predictive techniques, the outcome of any restoration effort will be necessarily uncertain (Cairns 1990). Monitoring and assessing crucial ecosystem functions will indicate whether or not changes in the restored system are progressing toward such successional maturity. (Assessing monitoring data for this purpose will require gathering additional information on the normal successional progression of restored ecosystems). When monitoring efforts suggest that restored ecosystem conditions are substantially different, a need for additional restoration may be indicated.

Many domestic and international restoration development projects are multiyear undertakings requiring an organized monitoring effort that will permit adjustments in future activities based upon new information. Restoration projects, which are often undertaken for both environmental and economic reasons, require frequent adjustments to the restoration actions based on many conditions. This does not mean that if the original process had to be altered the project goals were ill-conceived, but rather that the complexity of the system required flexibility in the implementation phase.

We should note that the successful abatement of risk to preferred goods and services is not necessarily the only measure of restoration success. Although undesired, when a carefully planned, executed, and monitored restoration effort fails, our understanding of ecosystem science, risk assessment, and restoration ecology can be advanced and subsequent efforts will be enhanced (Ewel 1987).

Finally, we suggest that an early consideration should be the anticipated results or future context of the effort of planning a complex restoration effort. This is because any application of ecosystem restoration will have its outcome only in the future. As the consequences of a restoration project proceed toward their outcome, the environmental, socioeconomic, and political contexts change, independently of the restoration actions. We are obliged to anticipate the changed context within which our actions will impact and the changed meaning that the results of our intentions will have in that future context (Riner 1990). What are and will be the environmental concerns in the 1990s and beyond? This is not a game of prediction, but rather the study of alternatives. It is a matter of choices among probable and preferable alternatives (Riner 1990). Speculation about the future context in which a ecological restoration program might be judged is beyond the scope of this paper; however, it seems apparent that a complex, long-term effort requires elements of future studies, planned flexibility, and expecting to be surprised.

Conclusions

A clear need exists to assemble a broad and objective perspective of the ecological and socioeconomic knowledge that is required to underlie a scientific approach to the problems of ecological restoration. Our current understanding of the nonequilibrium nature of ecosystems seems to preclude the selection of return to historic pristine conditions as a feasible goal for any restoration effort. In the absence of a simple historical option for establishing restoration goals, we believe that restoration planning requires a value-based, goal-driven decision system. Furthermore, restoration objectives must have unambiguous operational definitions, have social or biological relevance, and be accessible to prediction or measurement. We believe that landscape and holistic ecosystem perspectives should be included as integral parts of the decision system.

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