THEORETICAL CONSTRUCTS FOR LARGE-SCALE RESTORATION

AN ACCOMPANIMENT TO

GEOGRAPHY OF HOPE UPDATE

WHEN & WHERE TO CONSIDER RESTORATION IN ECOREGIONAL PLANNING, SEPTEMBER 2002

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SEPTEMBER 2002

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Saving the Last Great Places

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INTRODUCTION

Conservation biologists have described the need for addressing conservation at regional, continental, and even worldwide scales to meet the needs of wide-ranging species, maintain large-scale ecosystem functions and integrity, and understand the role of large-scale disturbances in conservation biology (Zedler 1996, Soulé and Terborgh 1999, Groves et al. 2000, 2002). In 1996, The Nature Conservancy embraced ecoregional planning as the appropriate spatial scale to define the task of conserving the full suite of biological diversity (TNC 1997). The Conservancy constructed a process that involved several critical steps at the ecoregional scale including a) establishing an interdisciplinary team to identify conservation targets including species, communities, and ecosystems b) setting numeric conservation goals for each target, and c) creating a portfolio of sites that most efficiently captures the targets and meets the conservation goals (Groves et al. 2000, 2002). Given that humans have altered an estimated one third to one half of the land on earth (Niering 1997), it is not surprising that in highly populated or intensely developed ecoregions it is impossible to meet all conservation goals solely by protecting existing high-quality habitat as habitat loss has been profound. For example, in Illinois while 28.8% of the original pre-settlement forest exists (Ebinger 1997), only .01% of the original tallgrass prairie remains (Robertson et al. 1997). Therefore, in areas where habitat loss and fragmentation have been profound, it is necessary to consider restoring degraded habitat to meet conservation goals (TNC 2000a).

The disadvantages of restoration, compared to protection of existing habitat, are many. Restoration can be expensive and time-consuming (Meffe and Carroll 1994, Lazaroff 1999, Holl and Howarth 2000, Lindig-Cisneros and Zedler 2000, Tear et al. 2000, Zedler 2000). Restoration ecology is in its infancy, and restoring degraded habitat carries with it a high level of uncertainty (Rapport and Whitford 1999, Sauer 1998, Whisenant 1999). In addition, much of the ecological restoration to date has been at a small scale or focused on the needs of particular ecosystems (Packard and Ross 1997). Less work has been done on addressing restoration at landscape, ecoregional, or larger scales (TNC 2000a, TNC 2000b, Simberloff et al. 1999, Hobbs and Norton 1996). Given these concerns, Geography of Hope Update #9 (*When & Where to Consider Restoration in Ecoregional Planning* – which will be released Aug 2002) addresses the following practical conservation questions:

1. Can restoration be an effective conservation tool across ecosystem types and at large scales?
2. Are there useful conceptual frameworks and guidelines to decide if restoration should be done in the context of conservation planning at large spatial scales?
3. What are the criteria for initiating successful large-scale restoration projects?

To address these questions, this background paper provides the context to understand the ecological, social, political, and economic principles and issues surrounding large-scale restoration. Building upon this conceptual foundation, we conclude with some suggested criteria for restoration success.

GUIDING ECOLOGICAL PRINCIPLES

The science of restoration is relatively new, but one that has captured the interest of scientists, conservationists, and practitioners resulting in a variety of publications including books, informal publications, and several peer-reviewed scientific journals. The Society for Ecological Restoration (SER), a scientific society formed in 1987, produces peer-reviewed journals such as *Restoration Ecology* and *Ecological Restoration* that are dedicated to restoration. In addition, broader scientific journals such as *BioScience* and *Conservation Biology* regularly publish articles on restoration. Large-scale restoration receives increasing attention by investigators who believe that we must restore entire systems in order to preserve biodiversity. This section highlights relevant issues of scale, achieving success, resiliency, landscape context, and species introduction related to large-scale restoration.

Issues of scale

While the majority of restoration projects have occurred at small spatial scales, there is a growing body of literature calling for restoration at scales that specifically address landscape-level disturbance patterns, the needs of wide-ranging species, and other large-scale phenomena (Simberloff et al. 1999). The exact size of large-scale restoration projects will be defined by a select group of key ecological factors or conditions as they apply to the restoration effort. Such factors include the necessary supporting ecological disturbance processes such as fire or flooding, the dominant climatic regime of the region and target area, species distribution and behavioral norms, and the range of natural vegetation communities characteristic of the target region (Anderson et al. 1999, Simberloff et al. 1999, Groves et al. 2000).

The evolution to large-scale restoration has been precipitated by the recognition that in many cases small-scale restoration efforts often fail to meet conservation goals if site-specific actions are not simultaneously supported by large-scale processes and inputs. Whisenant (1999) contends that restoration objectives "should include fully functional wildland landscapes that are self-repairing, and have strong auto-genic capabilities with minimal requirements for continuing subsidies." Without landscape-scale support, localized restorations can create unstable sites and landscapes (Whisenant 1999).

Despite this sentiment, most historical biodiversity restoration projects have been implemented at small spatial scales involving intensive restoration practices (Meffe and Carroll 1994). The National Research Council review of case studies (NRC 1992) concluded that most projects were conducted at small spatial scales and short temporal scales and involved a low level of assessment yet recognized that the ideal situation would be just the opposite: large spatial scale, long temporal scale, and high level of assessment (see also Zedler and Calloway 2000). For example, the prairie restoration project at the University of Wisconsin (UW) Arboretum in Madison, Wisconsin has one of the longest monitoring records of any restoration site. This project began in the mid-1930s under the leadership of Aldo Leopold and others. Since that time, volunteers and researchers have restored approximately 40-ha of prairie and conducted extensive monitoring (Robertson et al. 1997). More than 150 prairie species were planted during the 1940s and 1950s, and prescribed burning is a regular part of the management regime. Over time, plant species have segregated themselves according to optimum conditions. The prairie supports some 170 plant species (Lindig-Cisneros and Zedler 2000) and provides habitat for numerous bird, insect, and mammal species (Robertson et al. 1997).

The UW Arboretum restoration demonstrates that native plant communities can be restored to agricultural lands, and that prescribed fire can be used effectively to combat exotic plants and woody vegetation. However, this project, one of the oldest and best-documented restoration efforts, raises concerns for large-scale restoration. Despite success in supporting botanical diversity, some animals of the tallgrass prairie are still missing from the site, especially those conservative species that are tied to high-quality ecosystem remnants (Lindig-Cisneros and Zedler 2000, TNC 2001a). It is a small-scale project (40 ha) and may not be large enough to withstand a major disturbance. It has also had the benefit of time, repeated plantings, and intensive management – luxuries not likely affordable at a landscape scale. This example highlights the difficulties in returning the ecological system to its reference condition, yet demonstrates that it is possible to restore many attributes of ecological integrity. The UW project also illustrates the limitations of small-scale restoration. The landscape context of the Arboretum (i.e., its urban setting) limits site-level biodiversity because it is disconnected from potential sources of species immigration and the prairie's hydrologic condition has been permanently altered by urban stormwater run-off (Lindig-Cisneros and Zedler 2000).

The difficulties of "scaling-up" and of quantity-quality trade-offs have been the focus of some debate (e.g., Meffe and Carroll 1994, Simberloff et al. 1999). Scaling-up from small projects to large may entail sacrifices in biodiversity, under-representation of rare species, and higher proportions of exotic species as in the 250-ha prairie restoration at Fermilab in Batavia, Illinois (Meffe and Carroll 1994, Robertson et al. 1997). Although large-scale projects may be carried out at the expense of some system components, especially in the short-term, Meffe and Carroll (1994) offered reasons for hope in the long run. They suggest larger areas may have the advantage of more complete functional infrastructure and a greater capacity for self-repair, and "might be expected to improve gradually through what might be called 'subsidized succession" through timely species introductions and perpetuation of disturbance patterns "until they achieve an even higher quality than more intensively restored, small-scale projects." They noted that large-scale restorations typically involve the manipulation of fire regimes, grazing, or hydrological processes rather than intensive revegetation or other high-cost activities typical of small-scale restoration projects (Meffe and Carroll 1994).

Despite this, some proponents of hierarchy theory have warned that landscape-scale restoration activities may have little effect on natural communities and other small-scale components (Allen and Hoekstra 1987). Others have argued that by focusing on a small suite of species referred to as "focal-species" that are most influenced by the processes that threaten the landscape, that large-scale restoration efforts can be efficiently and effectively guided – particularly in fragmented agricultural landscapes where the concept originated (Lambeck 1997, 1999, 2002). This taxon-based surrogate approach has been criticized for a variety of reasons, many related to interpretation of ecological hierarchy issues (Lindenmayer et al. 2002). It is important to continue restoration activities at large and small scales to ensure that restoration and assessment needs are met across the spectrum of spatial and temporal scales.

Achieving Success – Defining, Measuring, and Assessing Progress

Many past restoration projects have been implemented on a trial-and-error basis with no provisions made for research, experimentation, or effective monitoring plans. This can be avoided by considering four issues to define success in restoration: 1) rigorously assess the viability of our conservation targets; 2) set realistic, measurable goals based on desired future conditions; 3) implement monitoring, evaluation, and adaptive management; and 4) incorporate research into restoration. These steps should be viewed as a programmatic or process measures for effective restoration.

Landscape Assessment – Viability at Large Scales

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Numerous ecologists have identified the need to assess and compare landscapes as a requisite to effective restoration planning, and many methods for landscape assessment have been proposed (NRC 1992, Hobbs and Norton 1996, Packard and Ross 1997, Aronson and Le Floc'h 1996, Naveh 1998, Lindig-Cisneros and Zedler 2000, McDonald 2000). The ability to characterize the ecological condition of landscapes can help determine the restorability of individual sites, identify priority sites for restoration in a regional context, set goals for restoration, and measure the success of restoration efforts over time.

The Nature Conservancy has adopted a method for assessing the viability of target species, communities, and ecosystems based upon the size, condition, and landscape context of the conservation target (Anderson et al. 1999, Groves et al. 2000, TNC 2000c). Nested within size, condition, and landscape context are a comprehensive suite of biotic and abiotic factors affecting the viability of the conservation targets. In the context of ecoregional restoration, viability analysis provides a picture of the current ecological quality of a restoration target for comparison with historic or desired ecological conditions. Such a comparison will help define the goals for restoration by highlighting causes of degradation and focusing on steps necessary to improve viability.

Setting Goals for Restoration

Assessing the viability/integrity of conservation targets sets the stage for establishing quantitative restoration goals. Defining goals and criteria for measuring success in achieving those goals has been a central issue in restoration literature (Aronson and Le Floc'h 1998, Simberloff et al. 1999, Ehrenfield 2000, Hobbs and Norton 1996), but agreement on what the goals should accomplish has varied widely (Ehrenfield 2000). Despite these differences in opinion, several important considerations have emerged:

- Goals and objectives should be made explicit to a particular spatial scale (e.g., local to regional scale following Poiani et al. 2000). These goals and objectives may vary greatly and may depend on the level of degradation present.
- The criteria for success must be measurable and have specific timelines for attainment.
- Restoration practitioners must ensure that ecosystem processes do not become the end goal at the expense of species diversity.
- Restoration goals should be operational. We must be able to specify activities and strategies that will lead toward achieving the goals (Simberloff et al. 1999).

In one example of landscape-level goal-setting, Whisenant (1999) categorized fundamental considerations into "repair goals" as follows: a) site stabilization and repair of primary processes; b) propagule dispersal, animal interactions, and pollination requirements; c) and microenvironmental modification. Hobbs and Norton (1996) cited other objectives including "density of dominant plant species, structural diversity, [and] recolonization by native fauna." In an ecoregional planning context, each target considered for restoration should have clear goals tied directly to improving target viability by improving one or more of its components (i.e., size, condition, landscape context) and ultimately contributing to meeting the ecoregional plan's numeric (i.e., the number and distribution) goals.

Monitoring, Evaluation, and Adaptive Management

Effective monitoring requires establishing clear, measurable goals and objectives for set time periods (Cairns 1995, Hobbs and Norton 1996). Monitoring and evaluation are "iterative processes that provide the feedback necessary for improvement" of landscape restoration efforts (Whisenant 1999). When measurable progress toward restoration goals is not made, monitoring information is essential in adapting and improving management (Whisenant 1999). Also, monitoring and evaluation not only help us improve individual projects, but also add to the wider body of restoration knowledge (Landers 1997).

Measuring success is especially important to large, long-term restoration projects because of their complexity and management flexibility (i.e., adaptive management) should be part of the design at the front end (Whisenant 1999). Because information is expensive to collect, store, retrieve, and analyze, monitoring programs should be designed early on in the restoration planning process (Cairns 1995, Whisenant 1999), and they should be designed to collect information in sufficient, but not excessive, detail (Whisenant 1999). Landers (1997) emphasized that monitoring should figure prominently in budgeting for restoration at the outset.

In ecoregional planning, establishing baseline conditions and reference conditions are key factors in measuring the success of restoration efforts. Baseline conditions are a basis on which to compare progress of restoration against the conditions present before restoration began. Reference conditions allow for comparison of restored conditions to either historical data from the restoration site or contemporary data from sites that closely match the natural conditions desired of the restoration site (Whisenant 1999). It should be noted, however, that while reference sites guide the restoration process, they are not sufficient in and of themselves. Restoration practitioners must develop clear objectives defined by acceptable minimum measures of ecological structure (including species composition) and function.

Incorporating Research into Restoration

Whenever possible, a research component should be built into large-scale restoration efforts. This issue has been posed as both a means of furthering our knowledge for the sake of ecology (Jordan et al. 1987) and for furthering our knowledge for the sake of applied restoration (Simberloff et al. 1999,

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Clewell and Rieger 1997). Among the research topics that need more study, Clewell and Rieger (1997) cite:

- Inventories of past projects
- Criteria for defining reference ecosystems
- Criteria for site-selection
- Invasives and exotics
- Ways to measure success
- Cost effective restoration methods

Although it is not possible to incorporate research on all of these topics, Conservancy practitioners and partners should seek to use scientific methods wherever possible. Large-scale conservation areas offer many opportunities to design the restoration project as an experiment that tests alternative restoration actions. This "adaptive restoration" approach (sensu Zedler 2001) allows evaluation of the actions that are most effective, as well as insights into cause-effect relationships. In doing so, it simultaneously provides restoration actions while improving the science of restoration. Excavating replicate areas with and without tidal creek networks in Tijuana Estuary's 8-ha restoration of tidal marsh is a good example (Zedler 2001). Larger restoration projects can be designed as experiments, with replicate areas left unrestored initially, while alternative actions are used as "treatments" in other replicate areas. The larger the site, the more opportunity there is for adaptive restoration. Phasing the project, so later modules can incorporate findings from earlier experiments, further accomplishes adaptive restoration (Zedler 2001).

In addition, Cairns (1995) identified peer review and communication of results to the general public as critical ingredients of effective restoration monitoring. By expanding the restoration knowledge base through peer-reviewed journals and other public media we can improve conservation efforts both inside and outside the Conservancy while increasing our credibility in the scientific community.

Resilience – Relying on Natural Processes

Working with the resilience of natural systems should be a cornerstone of large-scale restoration activities because they can minimize the risk of further deleterious alterations to disturbed ecosystems and maximize the effectiveness of limited financial resources. The best recourse in restoration may be to rely on the resilience of natural systems to regenerate themselves, applying only "critical, minimal interventions" (McDonald 2000). Resilience may be a product of natural ranges of variability of processes and of natural disturbances. In some aquatic systems, natural disturbances include floods and spates that often re-set systems, and provide conditions only suitable for native species that evolved in response to these recurrent conditions.

In reviewing restoration projects across Australia since 1925, McDonald (2000) found that in many cases relatively simple interventions such as planting "perch trees" that attract seed-dispersing birds and bats was an alternative to planting entire plant communities at rainforest restoration sites. In other cases, weed control or prescribed burning alone was enough to spur on regeneration of native plant communities. McDonald makes the case that optimizing interventions based on ecosystem resilience provides a logical framework for more effective and economical restoration.

Relying on the resilience of the natural system can lead to greater fidelity of the restored system to the former pre-disturbance state while ensuring the continuity of complex components (McDonald 2000). The use of natural regeneration may also avoid wasteful spending on costly, intensive restoration measures. The degree of resilience will drive the degree of restoration intervention necessary, and the need to be able to determine the degree of resilience highlights the need for effective landscape assessment tools (Packard and Ross 1997, McDonald 2000). Obviously, removing the causes of degradation will be a key factor in the ability of the system to recover (Whisenant 1999).

Degradation Thresholds – When Resilience is not Enough

Although relying on the resilience of natural systems is a sound starting point for restoration, in many cases it will not be enough. The concept of degradation thresholds has merited consideration by various authors in the assessment of restoration potential (Aronson and Le Floc'h 1996, Hobbs and Norton 1996, Rapport and Whitford 1999, McDonald 2000, Zedler 2000). As Zedler (2000) observed, degradation and restoration do not proceed as straight arrows in opposite directions along parallel paths. Rather, degradation may proceed beyond threshold states, recovery from which may require extraordinary restoration measures. In some cases, highly degraded systems will not bounce back once stresses are reduced (Rapport and Whitford 1999). In these cases, degradation below a threshold state may trigger successional processes to divert from historic trends to new, altered trajectories, ultimately preventing the "return" to predisturbance condition. Hobbs and Norton (1996) described a degradation/restoration model in which ecosystems "undergo rapid transitions between different metastable states." Because of such thresholds, transitions leading to degradation may be easier to force than transitions leading to restoration (Hobbs and Norton 1996, McDonald 2000). In such cases, removing the cause of degradation may be a necessary, but not sufficient, measure in the restoration process (Hobbs and Norton 1996, McDonald 2000).

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Landscape Context – Connectivity, Abiotic Forces, and Unprotected Lands

In *Designing a Geography of Hope* (Groves et al. 2000), landscape context is defined as "an integrated measure of two criteria: connectivity to other populations and intactness of surrounding ecological processes and environmental regimes." While improving size and condition of conservation targets is largely the responsibility of conservation area planners, ecoregional planning can identify the need, and opportunities, to improve landscape context for target species, communities, and ecosystems. Large-scale restoration can be a critical conceptual tool for ecoregional planning in restoring connectivity of disjunct populations and communities or in reestablishing critical abiotic processes.

Spatial Configurations and Connectivity

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Many conservation biologists and restoration ecologists have identified a need for connectivity or linkages among habitat patches (e.g., Hobbs and Norton 1996, Sauer 1998, Beier and Noss 1998, Dobson et al. 1999, Whisenant 1999, Nabhan 2001). Fragmented "islands of nature" can lead to problems with nutrients and pollutants, invasive species, species migration, and ecosystem functions such as reduced pollination and seed dispersal and herbivore population explosions (Dobson et al. 1999). Of particular concern to large-scale restoration are problems associated with small populations and artificial metapopulations for which fragmentation leads to localized extinction rates that exceed recolonization rates. If not corrected, this ongoing phenomenon will create species-poor conservation areas that will not achieve biodiversity success. However, the question of how to provide connectivity, short of creating mega-reserves, has been a topic of heated debate (Beier and Noss 1998, Harrison and Bruna 1999).

In particular, the efficacy of corridors, or linear habitats linking larger blocks of habitat, has been the object of much discussion in the literature (see review by Beier and Noss 1999). Supporters contend that corridors may provide a cost-effective means of enhancing population viability of certain species by facilitating movement among habitats. Critics argue that corridors may promote the spread of diseases, catastrophic disturbances, or exotic species or attract animals into areas where the risk of mortality is high (Beier and Noss 1999).

Perhaps because of the controversy surrounding corridors, some authors have proposed using the terms "connectivity" or "linkages" to describe pathways between habitat patches (Sauer 1998, Dobson et al. 1999, Whisenant 1999). Connectivity can describe a broader array of linkages that may provide habitat and stop-over points at many scales, and may include so-called stepping stones or corridors greater than one home range in width rather than simply narrow linear corridors (Dobson et al. 1999, Nabhan 2001). For example, Nabhan (2001) described migratory corridors for winged pollinator species as "a mosaic of stepping stones within a larger matrix, with each stone a stopover that migrants use for 'refueling' while in transit along 2000-6000 km flyways." These stepping stones are critical not only for the migrants, but also for the sessile plant communities that depend on the pollinators to facilitate long-distance gene flow and for non-migratory pollinators that visit the same flowers and benefit indirectly from genetic mixing.

Nabhan (2001) contended that “the best way to ensure adequate connectivity in regional reserve networks is to better manage intervening private lands in a manner consistent with the needs of migratory wildlife.” Nabhan has restored habitat for migratory pollinator species on private farmland in the desert Southwest by planting wildflowers, creating artificial nests, and using other restoration techniques. He recorded twenty-five species of migratory pollinators and some 322 species of invertebrate pollinators that have benefited from these restoration efforts.

Remnants should play a critical, cornerstone role in restoration around which connectivity or linkages are designed or built. Remnants can be defined as ecological communities or systems that retain many components of their natural character (Packard and Ross 1997). Such remnants are likely to represent the targets that drive specific restoration approaches at sites. Huxel and Hastings (1999) found that locating restoration sites adjacent to existing sites occupied by a target species could increase patch occupancy of the restored sites by six-fold over randomly located sites in early phases of restoration. They suggested that adjacency is especially important for less vagile species, while for more vagile species restored patches might be placed to maximize connections between existing occupied patches. Others have recommended creating patches of “attractant plants” or planting “perch-trees” to attract seed-dispersing animals as an effective means of reconnecting habitat while accelerating succession (Whisenant 1999, McDonald 2000). Similarly, reintroduction of pollinating species and improving habitat for such species may be another cost-effective method of restoration (Nabhan 2001). Whisenant (1999) emphasized spatial diversity because size and shape of boundaries between landscape patches affect rate and direction of successional processes.

Remnants play a crucial role in restoration, particularly in highly degraded systems such as the tallgrass prairie of the Midwestern United States (Packard and Ross 1997, Robertson et al. 1997, Tear et al. 2000, TNC 2000a). Historically, restoration has focused on improving the ecological condition of remnants themselves, but has increasingly recognized functioning residual patches as a resource for larger-scale restoration outside the remnant boundary.

Protecting intact remnants is usually cheaper and easier than restoring damaged sites (Landers 1997). Tear et al. (2000) suggested, “natural vegetation community restoration should not be focused at creating ’new’ element occurrences, but supporting existing remnants by enhancing their viability through improving landscape context and connectivity with other sites.” Remnants provide not only the raw materials for regenerative processes in restoration, but also critical information regarding the pre-disturbed condition (Meffe and Carroll 1994, Landers 1997). Robertson et al. (1997) lauded the movement toward restoring larger, degraded sites with restoration potential, but also remarked on the continuing need for protection and enhancement of smaller, high-quality remnants.

Adding Connectivity to Ecoregional Portfolios

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In a discussion paper for the Conservancy’s Northeast/East working group on connectivity, Anderson (2001) provided a review of connectivity and suggested “connectivity between reserve areas should not be considered a substitute for the conservation of large contiguous areas.” Furthermore, habitat fragmentation is a degradation problem, stemming largely from edge effects, rather than a dispersal problem that could be rectified through increased connectivity or optimal spatial configuration of fragmented habitats. He concluded that corridors should complement, rather than replace networks of large reserves.

With regard to adding connectivity to ecoregional plans in the Northeast/East U.S., Anderson made two recommendations. The first was that occurrences of matrix and patch communities that fall below viability standards should either be excluded from ecoregional portfolios or restored in size to meet the standards. The second was that developing connections between occurrences that meet viability standards may be necessary in maintaining species and processes within networks, but that there is a need to be specific about the systems, processes, and species targeted by improved connectivity.

Abiotic Forces

Important abiotic forces in large-scale landscapes include fires, floods, hurricanes and other major storms, rare freezes, and geologic events such as erosion, earthquakes and volcanic eruptions (Simberloff et al. 1999). In addition, there are predictable, variable flow and temperature regimes in river systems that are not as well described as floods (J. Higgins pers. comm.). Within these abiotic forces some can be manipulated or controlled to an extent (e.g., fires and floods), and restoration efforts are aimed at mimicking natural regimes. Others are beyond human control (e.g. hurricanes, freezes, and geologic events), and restoration efforts are aimed at providing habitats of sufficient size and appropriate configuration to allow such events to create a spatial mosaic of adjacent, heterogeneous patches (Anderson et al. 1999, Simberloff et al. 1999).

Identifying those processes that may be manipulated is the first step in restoration. According to Simberloff et al. (1999), managers should consider restoration actions only for those processes, "that can be controlled or reintroduced at reasonable cost and within appropriate time frames." Examples of abiotic processes we can manipulate include fire, nutrient cycles, hydrology, erosion, and sedimentation (Whisenant 1999, Simberloff et al. 1999). Restoring abiotic processes may encounter considerable human opposition, especially to controversial actions such as restoring natural flood or fire regimes.

Restoring natural flood regimes. The National Research Council (NRC 1992) identified the Illinois, Upper Mississippi, and the Atchafalya Rivers as three examples in the U.S. of large-floodplain rivers with the potential of fluvial restoration. While the natural process of seasonal flooding is still in place on these rivers, river access to large proportions of the floodplain is an issue. Allowing these rivers to flood over their banks, and reclaim land behind levees that was historically floodplain would improve the river system as a whole by returning critical ecological processes and connectivity of habitat. This approach takes the long temporal view to restoration, and emphasizes the importance of landscape context to restoration at large scales – to support ecological processes influencing sites. Meffe and Carroll (1994) noted that working at larger scales and restoring ecological processes (e.g., fire, grazing, and hydrology) may develop a greater capacity for self-repair.

Restoration of natural fire regimes has received much attention in the literature (Baker 1994, BLM 1999, Holmes and Richardson 1999, Simberloff et al. 1999, BLM 2000, Bowler 2000, McDonald 2000, Radeloff et al. 2000). The historic fire season of 2000, including the Los Alamos fire in which a prescribed burn raced out of control, has brought much public attention to fire manipulation and suppression as well, compounding fire's ecological complexities with socioeconomic controversies. The challenge for restoration practitioners is to recreate the ecological integrity lost through altered fire regimes while addressing societal concerns for safety and property.

There is no silver bullet in managing fire because the alterations in fire regimes vary widely. Even within grassland ecosystems, fire regime problems vary from encroachment by woody vegetation brought on by fire suppression (Packard and Ross 1997) to replacement of native perennial grasses by invasive annuals due to accelerated fire cycles (BLM 1999, BLM 2000). Some ecosystems require frequent, low-intensity ground fire, as in long-leaf pine and ponderosa pine communities, while others require irregular, high-intensity, stand-replacement fire, as in Florida sand pine scrub communities (Simberloff et al. 1999). As such, characterizing natural fire regimes and their effects on ecosystem function will be fundamental in designing effective fire management plans.

Unprotected Lands

Much of the literature on large-scale ecological restoration has focused on lands that are, or will be, set aside for conservation purposes. However, a number of authors have called for a more-generalized re-integration of human activities with the natural landscape. Naveh (1998) described a classification system encompassing all "human ecosystem landscapes" from the pristine to the industrial and recommended restoration strategies for each. Sauer (1998) called for restoration of rights-of-way as corridors in a network of habitats and for restoration of the landscapes "where we live and work" including gardens, parks, greenways, cemeteries, and golf courses.

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Such generalized views bring together concepts of cultural and ecological restoration and call for a paradigm shift in the human relationship to nature; from one of dominance to one of ecological sustainability. A key factor in considering the restoration of urban, suburban, and agricultural lands is weighing the opportunity cost of expending limited resources on such marginal lands (while lands with more restoration potential are neglected) against the potential benefits of education and nurturing a more sustainable relationship to the land.

Timberland example. Some ecologists have suggested it may be possible to meaningfully restore ecological values to productive timberlands (Lamb 1998, Radeloff et al. 2000). Lamb (1998) described a variety of restoration measures and management techniques that could restore native biodiversity to industrial timber plantations in tropical regions. Restoration measures included planting native rather than exotic species, creating natural buffer strips between plantation patches, creating species mosaics or mixed species plantations, and allowing plant understories to develop. While these measures could improve the ecological condition of such plantations, they would not restore them to pre-disturbance conditions. From an economic standpoint, such measures would require significant management changes and could lead to increased costs and decreased productivity, though not as a matter of course (Lamb 1998).

Riparian example. Another example is the many mainstem rivers that are unprotected and serve as transportation waterways (e.g., Illinois River). Certain human uses are compatible with conservation needs. Focusing on unprotected waterways as corridors for animal movements and for sources of hydrologic pulses is critical to maintaining aquatic biodiversity (J. Higgins pers. comm.).

Many issues regarding restoration of unprotected lands are simply an extension of the general questions of restoration ecology. Landscape assessment, restoration goals, connectivity, and other issues figure into the equation. If regional goals for conservation targets cannot be met through protection or through restoration of protected lands, perhaps the only alternative is to integrate ecological restoration with agricultural, residential, or industrial landscapes.

Key Ingredients – Control of Invasives, Reestablishment of Natural Disturbance Forces, and Reintroduction of Native Species

Simberloff et al. (1999) identified three categories of restoration methods necessary for regional and continental restoration: 1) control of invasive nonindigenous species, 2) reestablishment of natural abiotic forces, and 3) reintroduction or augmentation of native species. (See Landscape Context section above for a discussion of abiotic forces). This framework of methods for large-scale restoration contrasts with the predominant small-scale practice of introducing or reintroducing a small number of native (or sometimes fast-growing non-native) species in an effort to accelerate community succession.

Invasive Species

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Invasive species are a pervasive and persistent problem in many restoration landscapes (BLM 1999, Simberloff et al. 1999, BLM 2000, McDonald 2000). Invasives include opportunistic native and exotic species of plants, animals, fungi, and microorganisms. Species from each of these groups have severely altered ecological communities (Simberloff et al. 1999).

In the Great Basin of the western United States, exotic annual grasses now dominate up to 25 million acres (10 million ha) of land, replacing once diverse desert communities comprised of sagebrush and salt-desert shrub overstories, understories of perennial grasses and forbs, and biological crust formations on the soil (BLM 2000). It is estimated that noxious weed infestations are growing by at least 14 percent annually in the Great Basin, and annual grasses are not the only culprits. In 1964, rush skeletonweed (*Chondrilla juncea*) comprised a few plants in Idaho; this weedy forb now covers some 4 million acres (1.6 million ha) (BLM 1999). Exotic invaders have robbed the soil of nutrients and water, changed the structure and dynamics of plant and wildlife communities, and altered fire cycles (BLM 1999). The case in the Great Basin is truly a regional problem on a scale at which we have never before been successful in controlling non-indigenous species.

Other ecological horror stories resulting from exotics abound including melaleuca (*Melaleuca quinquenervia*) in Florida, salt tamarisk (*Tamarix* spp.) in the southwestern United States, and feral pigs (*Sus scrofa*) in many places including Hawaii. Invasions by these species have led to the local extirpation of native species and radical alterations of habitat (Simberloff et al. 1999).

Many observers have noted that completely eradicating pest species may be impossible in many ecosystems, and that efforts should be aimed at controlling them while emphasizing strategies that favor native species (Landers 1997, Simberloff et al. 1999). Research by McDonald (2000) suggests that in many instances control of weedy vegetation may be sufficient for regeneration of native vegetation without the need for extensive plantings by humans.

The other two major methods of control are mechanical removal and chemical treatments. For most exotic species we lack the technology for eradication, although control is often feasible. Control measures must account for species-specific dispersal methods and life cycles while allowing for recolonization by native plants. Other difficulties include interest group opposition to removal of exotic species as in the cases of the monk parakeet (*Myiopsitta monachus*), feral hogs, and even eucalyptus (*Eucalyptus* spp.) (Simberloff et al. 1999). Compounding these problems is the high mobility of human societies which facilitates the movement and establishment of non-indigenous species (Simberloff et al. 1999). The good news is that only a small fraction of non-indigenous species becomes problematic for natural communities, allowing us to focus efforts on the damaging few.

As a regional restoration strategy for controlling exotics, Simberloff et al. (1999) recommended first developing action priorities based on thresholds of damage. The next step is to identify feasible control measures. Here they emphasized a regional view including restoration of disturbance regimes and reintroductions of key species rather than piecemeal eradication methods. When site-specific control measures are necessary, they should be done in the context of regional planning, especially for weeds that disperse well and reproduce rapidly. In such cases, all populations within dispersal distance of each other must be contained at once or the remaining populations may rapidly recolonize treated areas (Simberloff et al. 1999).

Reintroducing Native Species

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Simberloff et al. (1999) cite three broad goals for reintroducing native species in large-scale restoration:

1. To restore the original structure and relative abundances of dominant species;
2. To reintroduce species that are often rare and of little-known overall importance to ecosystem function; and
3. To provide services for other species of critical importance (as forage, cover, and so forth).

They note that reintroductions at a regional scale differ from site-specific attempts that have historically focused on restoring a few dominant native plant species or simply re-creating a generic functioning ecological community without regard for the predisturbance condition. For purposes of regional conservation, efforts should focus on improving and expanding extant native communities. Restoration should also include reintroduction or augmentation of keystone animal species, such as beaver (*Castor canadensis*) that play important roles in shaping ecosystem function and structure (Hobbs and Norton 1996, Simberloff et al. 1999, Whisenant 1999). Whisenant (1999) noted that emphasizing process over structural repair does not preclude the reintroduction of native species, just that species reintroductions should focus on functional roles in addition to adding biodiversity value.

Important considerations in reintroducing native species include scaling up horticultural techniques to meet landscape level needs, incorporating disturbance regimes in planning for population persistence, establishing sufficient population densities of reintroduced species, and understanding priority rules governing community assembly (Hobbs and Norton 1996, Simberloff et al. 1999). Because of the low supply of rare species and the uncertainty associated with reestablishment, reintroduction of such species should be delayed until disturbance regimes and healthy populations of dominant species have been reestablished (Hobbs and Norton 1996, Simberloff et al. 1999).

Colonization by native species may occur naturally following removal of the causes of degradation if seed banks remain in the soil or if adjacent remnants have sufficient dispersal capability (Hobbs and Norton 1996, McDonald 2000). However, in many cases natural regeneration must be augmented (Meffe and Carroll 1994, Hobbs and Norton 1996, Holmes and Richardson 1999, Whisenant 1999, McDonald 2000). Among the strategies for effecting landscape level recolonization of native species, Whisenant (1999) recommended planting propagule donor patches, increasing animal dispersal of propagules, and increasing the effectiveness of wind as a natural transport mechanism.

Planting numerous small donor sites distributed over the landscape may provide a continual source of propagules and may be more effective than creating a smaller number of large stands. Techniques for encouraging animal dispersal include planting attractant plants that provide food, shelter, or perching sites for seed-dispersing animals (Whisenant 1999, McDonald 2000) or the selective use of livestock in some environments (Whisenant 1999). Animal dispersal techniques tend to favor reintroduction of some species over others, so restoration sites may have to be augmented with desirable plants or controlled for weeds (Whisenant 1999, McDonald 2000). Other issues surrounding animal management include managing herbivory, discouraging predation of planted seed, and attracting pollinators. Strategic planting of desirable wind-dispersed species in areas of high topographic relief with prevailing winds that blow over targeted sites may also encourage recolonization (Whisenant 1999).

As with restoration projects in general, species-specific reintroductions are long-term, risky undertakings that require sufficient monitoring to document success (e.g., Stanley Price 1989). Landscape-scale issues relevant to success include not only ecological issues of habitat suitability, but behavioral issues of social structure (Tear and Ables 1999), learning and experience (Tear et al. 1997). Adaptive management is necessary to incorporate knowledge gained through such long-term efforts, and sufficient funds be made available to sustain adequate monitoring programs so that the feedback loop to altering management actions is possible (Tear and Ables 1999). In addition to ecological concerns, social, political and economic factors must be adequately addressed for reintroductions to succeed (Tear and Forester 1992, Beck et al. 1994).

SOCIAL, POLITICAL, AND ECONOMIC FACTORS

Social Considerations

Restoration practitioners have increasingly recognized the need to incorporate human needs and concerns into restoration planning. As Geist and Galatowitsch (1999) observed, "The reasons for restoration failure, including cost constraints, limitations in land allocation, and insufficient time and labor, often involve underlying human obstacles." In fact, the necessary role of social, political, and economic factors to be included in planning and implementation has been recognized as a critical factor in success (e.g., Tear and Forester 1992, Beck et al. 1994).

One key to long-term restoration success is developing a human commitment to restoration (Geist and Galatowitsch 1999). Factors in developing such a commitment include developing a human relationship of caring about nature, developing cohesiveness among project participants, and fostering supportive interaction among participants (Geist and Galatowitsch 1999). Wyant et al. (1995) noted that the social desire for ecological restoration is well-articulated in the form of nearly 50 federal laws in the U. S., but that choosing among restoration goals remains problematic due to conflicting stakeholder interests. The fundamental question for restoration planning is how we weigh ecological restoration alternatives in relation to other management options.

Stakeholder education is critical to meaningful involvement in ecological restoration. As Cairns (1995) opined, "until environmental literacy is markedly improved in society as a whole, it seems unlikely that large-scale ecological restoration efforts will succeed and persist." In order to participate in restoration goal-setting, community members must understand what uses the ecosystem can sustain (Wyant et al. 1995, Whisenant 1999) and perceive potential human benefits resulting from restoration (McGurrin and Forsgren 1997, Geist and Galatowitsch 1999). Analysis of social context should include an assessment of local knowledge and implementation of appropriate education efforts (Wyant et al. 1995, Whisenant 1999).

Issues of scale may well be as important in the social context as they are in the ecological context of large-scale restoration. Restoration at a regional scale will usually involve multiple jurisdictions, multiple stakeholders, and multiple land uses (Ford et al. 1990, Landers 1997, Simberloff et al. 1999, Whisenant 1999). Incorporating the interests of landowners, agencies, non-profits, and business is likely to make compromise necessary. Effective communication, good technical information, and well-articulated goals will be essential in reaching acceptable compromises (McGurrin and Forsgren 1997).

The technical, socioeconomic, and climatic uncertainties associated with ecological restoration are often cited as a focal point in human obstacles to success (Wyant et al. 1995, Sauer 1998, Whisenant 1999). In describing the need to confront uncertainty, Sauer (1998) quoted Ludwig, Hilborn and Waters (1993): "We must consider a variety of plausible hypotheses about the world: consider a variety of possible strategies; favor actions that are robust to uncertainties; hedge; favor actions that are informative; probe and experiment; monitor results; update assessments and modify policy accordingly; and favor actions that are reversible."

Concepts and tools drawn from the social sciences and effectively applied may help to provide the information, knowledge, and direction needed for landscape-scale restoration efforts to succeed. A recent review of social science tools of relevance to the Conservancy provides a firm starting point for practitioners (TNC 2001b).

Collaboration is Key to Success

Numerous authors have identified the importance of developing partnerships in implementing large-scale restoration (McGurrin and Forsgren 1997, Holl and Howarth 2000, Tear et al. 2000). Partnerships encourage a pooling of resources and information exchange, foster project support and ownership, and often accurately reflect who benefits from restoration (McGurrin and Forsgren 1997, Geist and Galatowitsch 1999, Holl and Howarth 2000).

McGurrin and Forsgren (1997) recognized the necessity of collaborative efforts to ensure restoration success, but also acknowledged the difficulties in matching the social, economic, and cultural objectives of multiple organizations. The National Research Council (NRC 1992) stated, "The politics and consensus building required for integrated management of the resource are often as complex as the ecosystem itself." Effective communication is critical so that partners and other stakeholders understand and support restoration efforts (McGurrin and Forsgren 1997). Other key factors in collaborative efforts include leadership and effective organization. The presence of an individual or small group with vision, energy, persistence, and communication skills is a common element in many successful restoration projects (McGurrin and Forsgren 1997).

The Role of Government – Limits of Legislation

McGurrin and Forsgren (1997) posited that, "legal and regulatory systems create the social framework for restoration." Federal U. S. laws such as the National Environmental Policy Act, the Endangered Species Act, Clean Water Act, Clean Air Act, National Forest Management Act, and Federal Land Policy and Management Act along with various state and local laws have established specific environmental standards and restrictions and given citizens a say in how such laws are applied (McGurrin and Forsgren 1997). Federal programs such as the Conservation Reserve Program, Conservation Reserve Enhancement Program, and the Wetland Reserve Program have effectively created restoration projects in agricultural lands across the country (Holl and Howarth 1999, Zedler 2000). Restoration practitioners should be aware of environmental laws and regulations and governmental programs both for compliance considerations and as potential sources of restoration funding. These programs have been widely used to fund Conservancy restoration efforts in the Midwest (M. Reuter, pers. comm.).

Despite the considerable contribution government mandates have made in providing a social framework and funding for restoration, various authors have noted the short-comings of such mandates (Cairns 1990, Karr 1994, Zedler 2000). Cairns (1990) remarked, "Of all the dilemmas in the restoration process, it is possible that developing adequate legislation is the worst." Widespread and persistent poor management in the past has led to highly prescriptive legislation calling for compliance with specific standards. Yet the outcome of restoration projects is inherently uncertain, and it may take many years for restoration efforts to bear fruit (Cairns 1990, Zedler 2000).

Economic Factors

McGurrin and Forsgren (1997) derived a simple principle necessary to successful watershed projects: "Perceived values of restoration must exceed perceived restoration costs." One difficulty in promoting this perception is that the benefits of restoration are often difficult to quantify and accrue over long time frames. These values may conflict with short-term resource use opportunities that are relatively easy to quantify. They also note that perceived values often galvanize around a focal issue rather than a comprehensive assessment of project costs and benefits. While the perceived values include the physiological, psychological, and spiritual benefits described by Geist and Galatowitsch (1999), economic values will often play a critical, even dominant, role in decision making.

The question of who pays for restoration is a fundamental concern. Various mechanisms have arisen to pay for restoration including "polluter pays" models, taxation, and voluntary donations (Shabman 1995, Holl and Howarth 2000). Under "polluter pays" schemes the party responsible for degradation pays for the cost of restoration, ideally before (as in environmental assurance bonding) but sometimes after the disturbance (as in Superfund sites). Public funding is often justified by the public services functioning ecosystems provide such as erosion control, improved water quality, and carbon sequestration. A major concern with publicly funding restoration efforts is ensuring the stability of funding sources. Public funding for restoration is often subject to political changes that can affect levels of funding appropriations (Doppelt 1997). This is an issue of fundamental concern to projects that are long-term by nature.

Volunteer donations contribute to restoration in a variety of ways including direct funding of restoration projects administered by local watershed councils or regional, national and international non-profit organizations. Donations also include contributions of volunteer labor, which in addition to their quantifiable in-kind value foster community education and stewardship ethics (Sauer 1998, Holl and Howarth 2000). Volunteer donations may also come in the form of landowners implementing best management practices or participating in cost-share programs for implementing habitat improvement measures (Holl and Howarth 2000).

Shabman (1995) and others have advocated harnessing market forces to fund restoration efforts. Market exchanges might be useful in reallocating water rights for restoration purposes in the western U.S. or for trading pollution credits to restore air and water quality and reduce emissions of greenhouse gases. Opportunities for tapping market forces for restoration might be realized by 1) removing policy distortions from the market, 2) imposing development fees, and 3) establishing transferable pollution rights (Shabman 1995).

SUMMARY AND CONCLUSIONS

At the outset of this appendix, we posed three questions that the review would address:

1. Can restoration be an effective conservation tool across ecosystem types and at large scales?
2. Are there useful conceptual frameworks and guidelines to decide if restoration should be done in the context of conservation planning at large spatial scales?
3. What are the criteria for initiating successful large-scale restoration projects?

There is no clear answer to the first question at this time. While we have described examples of successful restoration projects at small scales and of large-scale projects underway, we cannot point to a single large-scale restoration project as a resounding success in returning critical structures and functions to an entire landscape. This is not because efforts have failed, but that sufficient time has not passed to enable effective evaluation. It is possible to look at the recovery of large systems, such as Lake Erie since the passage of the Clean Water Act, and be assured that the assumption that large scale recovery is possible appears valid.

Large-scale restoration is an inherently complex undertaking associated with numerous technical, climatic, and socioeconomic uncertainties. Many of the theories upon which landscape level restoration is based remain untested because we lack examples of projects that have truly restored ecological function and structure to large damaged areas. There is a pressing need for experiments designed to test such theories, yet limited funding often limits the degree to which restoration practitioners can monitor and evaluate project success.

Despite these uncertainties there is a general consensus among restoration ecologists, and a growing recognition among conservation biologists, that large-scale restoration must be used if we are to preserve biodiversity at regional and continental scales. Some landscapes have sustained such great losses of function and structure that conservation of species, communities, and ecosystems cannot be achieved through protection alone.

Therefore, we believe there are useful conceptual frameworks and guidelines for making decisions regarding large-scale restoration. Although large-scale restoration is in its infancy, past projects – carried out at varying scales and with varying degrees of success – provide a foundation for future efforts. Lessons learned from an array of disciplines including conservation biology, restoration ecology, landscape ecology, landscape architecture, sociology, and economics have contributed to an increasing understanding of effective strategies for large-scale restoration. Investigators from these disciplines have made considerable progress in outlining logical decision-making processes for planning and implementing regional restoration and have addressed issues of site selection.

Finally, the following criteria for success summarize principles and guidelines for large-scale restoration described by various authors (Tear et al. 2000, Whisenant 1999, Williams et al. 1997, McGurrin and Forsgren 1997, Hobbs and Norton 1996, Wyant et al. 1995). In practice, each of these criteria should be accompanied by a strategy - be it research, planning, protection, or government relations. Each criterion should ultimately take into account ecological, social, economic, and political factors at local, regional, and national levels to be effective.

Criteria for success in large-scale restoration efforts include:

1. Assess viability, identify causes of degradation, and devise strategies to remove or alleviate these threats to the conservation targets of concern.
2. Set explicit, detailed, and realistic goals and objectives at local and regional scales.
3. Work with natural processes.
4. Establish monitoring and adaptive management at the outset.
5. Coordinate restoration activities with broader land use and management strategies of partners and stakeholders.
6. Obtain support from the human community at local, regional, and national levels.
7. Identify long-term funding for implementation, monitoring, and outreach.

Many of the tools to carry out large-scale restoration are in place, though we have much to learn. By incorporating our extant knowledge and learning from projects already underway, large-scale restoration should be possible in many landscapes if the human community makes the commitment of resources necessary to restoration success.

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