# Restoration, Ecosystem

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# Restoration, Ecosystem

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*Ongoing changes to the earth's climate, disruptions of nutrient cycles, and changes in land use are expected to result in extensive disruptions to natural communities and ecosystems. These disruptions will likely result in the extinction of valued species of plants and animals and the loss of important ecological services. At the same time, the potential strategies for minimizing the effects of these changes on ecosystems at the regional scale are extremely limited.*

*Restoration of degraded ecosystems is one promising strategy for reducing the negative impacts of global change. Ecological restoration attempts to promote recovery of ecosystems damaged by human activities. Restoration is increasingly attempted in freshwater, wetland, grassland, and forest ecosystems. The results of these efforts have been mixed. Many restoration projects involve high inputs of time and money for each hectare restored and ongoing maintenance is frequently required. In many cases, the species that make up a community can be established but healthy ecosystem functioning is more difficult to restore.*

*In the future, restoration ecology will likely play an important role in speeding the recovery of ecosystems damaged by global change. While some of the difficulties facing ongoing restoration projects are likely to be overcome with time and effort, it is probable that future ecological restoration will be unable to restore degraded natural communities completely.*

Restoration and related land-management projects offer potential tools for mitigating some of the effects of global change on ecosystems. According to the Society for Ecological Restoration, "Ecological restoration is the process of assisting the recovery and management of ecological integrity. Ecological integrity includes a critical range of variability in biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices." This approach presents an attractive basis for addressing some of the effects anticipated from changes in climate, nutrient cycles, and land use patterns.

Around the globe, restoration efforts are underway to reverse the damages of historical land use to restore ecosystem services and natural diversity. Most projects are very small, but a few large regional programs are underway (e.g., restoring the hydrology of the Everglades (Florida, US) and restoring parts of the San Francisco Bay Delta, US). The ultimate goal of many restoration projects is to reestablish a community that existed prior to human disturbance. For the purposes of this article, we also include *rehabilitation* projects, where it is recognized that past conditions cannot be recreated. Instead, establishing some alternative ecosystem is the target. We also consider *reclamation* projects that attempt to create an ecosystem that will provide specific ecological services, such as constructing a wetland to treat runoff, without regard for the species composition or overall ecological integrity.

The typical goal of restoration ecology is to restore a past state. Yet the very nature of environmental changes at the global scale, especially global climate change, means that conditions in a given area are changing in such a way that they will no longer be appropriate for the communities of recent history. Instead, restoration will provide tools and experience to smooth 'the recovery and management of ecological integrity'. For a given area, the target ecosystem will be one consistent with the new and changing climatic conditions. Restoration may also be valuable in helping to preserve currently existing, distinct communities by establishing them in new areas where climate has become favorable.

In this article, we first review how restoration ecology is being applied in different types of ecosystems. For each ecosystem, we consider how global change is expected to affect species and communities and how restoration ecology might address problems that emerge. We focus on climate change, rather than other aspects of global change, because changes in climate are expected to affect virtually all ecosystems (Intergovernmental Panel on Climate Change, 1996), and because prevention measures that might reduce impacts of changing climate have not been widely adopted. The lack of prevention strategies increases the importance of approaches such as restoration that focus on minimizing or reversing negative impacts on ecosystems. Restoration has proven to be a useful tool for addressing ecosystem degradation due to non-climate components of global change such as acid or nutrient deposition and changes in land use. Next, we discuss how ongoing restoration efforts might be modified to prepare for future climate change. Finally, we discuss the limitations and advantages of restoration ecology as a strategy for helping ecosystems adapt to climate change. While restoration has many advantages over other possible strategies for mitigating the effects of climate change on ecosystems, it is clear that none of the currently available tools will be sufficient to avoid the negative effects of climate change.

## ECOLOGICAL RESTORATION AND POTENTIAL APPLICATIONS TO CLIMATE CHANGE

Traditionally, much of the focus of environmental science has been on removing sources of stress from the environment, such as removing toxic chemicals or reducing inputs of nutrients. Global climate change challenges this traditional approach in part because elimination of warming associated with global climate change presents formidable technological, social, and political obstacles. Because it is not likely that we will be able to reverse climate change in time to prevent widespread disruptions of ecosystems, it becomes necessary to find other means of reducing the negative impacts of climate change. One approach will be to speed the natural processes responsible for ecosystem recovery. We suggest that restoration, especially large regional projects, can help address these changes in the future. It is also possible for ongoing projects to incorporate actions that will help buffer ecosystems against the negative impacts of climate change.

Ecosystems will differ in how they respond to climate change, which would have far-reaching effects on natural ecosystems (Intergovernmental Panel on Climate Change, 1996). In general, the effects of climate change will act on populations and species. The tolerances of each species for changing climatic conditions will differ, but it is expected that many species will no longer be able to persist in part or all of their current geographic ranges (Intergovernmental Panel on Climate Change, 1996). Even species that can tolerate wide ranges of climatic conditions are likely to be impacted as their predators, competitors, and prey respond to climate change. In response, species might shift their geographic range to suitable areas, change their behavior so they are active at cooler times of year, or evolve to tolerate the new conditions. Species that fail to adjust to new conditions rapidly enough will become locally extinct.

Here we describe progress in ecological restoration in freshwater, wetland, grassland, and forest ecosystems. For each ecosystem type, we briefly outline special challenges they will likely face from changes in climate and outline how restoration might be applied to meet those challenges.

## Freshwater Ecosystems

Under generally accepted climate change scenarios, aquatic ecosystems face possible changes in both temperature and the amount of water available (Intergovernmental Panel on Climate Change, 1996). Freshwater systems are already severely challenged and contain large numbers of threatened and endangered species (Dobson *et al.*, 1997). Many aquatic organisms are sensitive to water temperature and will face increasing stress from changes in thermal regimes.

Efforts to rehabilitate degraded lake ecosystems date back many decades. Most early efforts were responses to excessive nutrient inputs and resulting eutrophication. Noteworthy examples include Lake Washington in Seattle, US and Lake Erie in the US and Canada, where reductions in nitrogen and phosphorus inputs produced dramatic improvements in water quality. Similar approaches will be most relevant where climate change exacerbates existing problems, such as increased nutrient loading due to increased precipitation or decreases in dissolved oxygen concentration due to higher water temperature.

Acid deposition is one component of global environmental change, and the scale of the efforts devoted to treating impacted areas suggests that substantial resources can be dedicated to regional restoration efforts. One approach to restoring lake ecosystems affected by acid deposition involves application of lime to neutralize acid (Schindler, 1997). In Sweden alone, 7500 lakes have been repeatedly limed as part of efforts to restore acidified lakes (Appleberg, 1998). Regular application of lime can moderate acidity but additional restoration, such as restocking of fish, is usually needed to restore communities fully (Schindler, 1997; Appleberg, 1998).

Changes in thermal characteristics of habitats will likely exacerbate the already high rates of endangerment of aquatic species (Dobson *et al.*, 1997). Many endangered and threatened aquatic species have geographic ranges that encompass a narrow range of thermal conditions and have limited abilities to disperse to new habitats. Rising water temperatures will tend to exclude fish species from areas where they now exist, while appropriate thermal habitats will occur to the north of current ranges. Restoration ecology could play a role in providing new habitats for those species in thermally appropriate areas. The slow rate of dispersal to new habitats, especially for species in isolated lakes, will severely limit the ability of fish to shift their geographic range in response to climate change. Translocations could speed the adjustment of dispersal-limited species. However, many of the existing problems in aquatic systems result from introductions of species by humans to new habitats. Introducing species to cooler waters would need to follow thorough research on the potential impacts to species already in place and acknowledgment of the ecological risks involved. Creation of new habitats in enclosed basins (reservoirs) may be one approach to minimize the risks from such assisted range extensions.

Of particular importance to future efforts will be improving techniques for dealing with invasions by nuisance species. Changes in water temperature will probably allow further expansion of the ranges of aggressive exotic species, exacerbating existing problems. Experience with aggressive invaders such as rusty crayfish *Orconectes rusticus* and zebra mussel *Dreissena polymorpha* as well as numerous aquatic plant and fish species shows the difficulties managers face in attempting to limit ecosystem damage caused by invaders. Introductions of predatory game fish have disrupted many unique communities, but significant restoration can be initiated if the fish can be eliminated (McNaught *et al.*, 1999). Unfortunately, attempts to control the species composition of aquatic communities, especially smaller, non-game fish, algae, and higher plants, have had limited success (Welch and Cooke, 1987) (*see* **Lakes and Rivers**, Volume 2).

## Wetland Ecosystems

Climate change threatens to stress wetland species through direct effects of temperature and carbon dioxide ($CO_2$) concentration and through changes in hydrology due to precipitation, evaporation and sea level changes (Michener *et al.*, 1997). Temperature increases are likely to damage wetlands that store carbon in the form of organic matter. Canadian peatlands and the Arctic tundra could release major quantities of carbon to the atmosphere through increased decomposition rates as a result of warming or drying (Intergovernmental Panel on Climate Change, 1996). Experiments with multiple factors and many types of wetlands are needed to make long-term predictions of community change, however. The hydrologic restoration of drained peatlands in advance of climate change would help buffer the globe against these impacts.

Small ponded wetlands and dry-end wetlands will be very sensitive to altered hydrology (Sorenson *et al.*, 1998). Because half of North America's waterfowl are reared in prairie potholes, and because duck production is directly correlated with the number of small ponds, there would be measurable impacts to waterfowl following changes in precipitation and evaporation (Sorenson *et al.*, 1998). The acceleration of current efforts to restore drained potholes throughout the Midwest could mitigate some of the negative impacts in advance, but biodiversity would still likely decline, as not all species return with renewed ponding (Galatowitsch and van der Valk, 1996).

Many wetlands have lost their natural water regimes, especially flood pulsing and the accompanying mechanical disturbances and nutrient influxes that invigorate floodplain wetlands (Middleton, 1999). In some cases, restoration may be accomplished simply by removing impediments to water flow (Gilbert and Anderson, 1998). Where dams permanently reduce flooding of wetlands, significant improvements can be achieved by periodic water releases that mimic seasonal floods (Vaselaar, 1997; Middleton, 1999).

Hydrological changes may be greatest for coastal wetlands, where sea levels in many areas may rise more than 0.5 m by 2100 (Intergovernmental Panel on Climate Change, 1996). Salt marshes will be lost where sea walls obstruct their migration inland and/or where sedimentation cannot keep pace with inundation. Restoration efforts would help mitigate future losses due to sea level rise. Methods include reestablishing tidal flow through removal of dikes, reintroducing species, and excavating new wetlands (Simenstad and Thom, 1996; Zedler, 1996a; Williams and Watford, 1997). Inundation problems can be combated by encouraging sedimentation and marsh building (Smit *et al.*, 1997) or accommodated by 'managed retreat'. In the latter process, levees can be breached to allow salt marsh to reestablish in low lying areas (Packham and Willis, 1997; Gilbert and Anderson, 1998) or broad inland buffers can be set aside to allow salt marsh migration up slopes.

One of the most damaging effects of climate change on coastal wetlands may be from increased storm frequencies and magnitudes. Extreme high tides can carry salts inland on to intolerant vegetation and soils. Salty soils will favor the inland migration of halophytes, which will be necessary to maintain salt marshes where sediment accretion cannot keep up with inundation (Michener *et al.*, 1997).

Species will likely migrate into newly inundated areas at different rates and be affected by different substrates and competitors inland, so some species may need to be translocated. The high-intertidal marsh of Southern California, US, is a good example of an assemblage that may need to be translocated in anticipation of sea-level rise. Three high-marsh perennials are already rare and they rarely reproduce from seed. *Frankenia palmeri* has only one natural occurrence in the US, but in Mexico it occurs in both salt marsh and upland areas. *Salicornia subterminalis* (= *Arthrocnemum subterminale*) and *Monanthochloe littoralis* are more widespread in Southern California but their populations have been greatly reduced by trails, roads, and other disturbances. These species show promise for experimental planting in upland buffers. Plants should be grown from seed to provide genetic diversity, so that selection could operate after tides begin to inundate the populations. The benefits (enhanced genetic diversity) and risks (contamination of local gene pools) of bringing in seed from Mexico would first need to be weighed.

Much of the motivation for restoring wetlands is to provide ecological services, such as nutrient removal and retention. Restoring specific functions is usually more difficult than simply reestablishing plant cover (Mitsch and Wilson, 1996; Simenstad and Thom, 1996; Zedler, 1996b), and even state of the art techniques cannot yet restore a heavily disturbed ecosystem to a specific, self sustaining state.

The most restorable sites are those with some remnant of natural topography, hydrology, or species composition. The return of the channeled Kissimmee River to its historical riverbed rapidly restored native wetland plant cover and attracted populations of desirable invertebrates, fishes, and birds in the pilot demonstration project (Toth, 1996). More challenging is the plan to restore water flows to the Everglades, as water supplies are finite and Southern Florida, US, metropolitan areas permanently divert much of the water that used to form the 'river of grass'. On the positive side, the US National Park System sustains a large area of native vegetation, and providing more water should help it persist. Least restorable is the San Francisco Bay Delta, a huge complex system of river channels (mostly leveed for flood control), water diversion canals (designed to move water to Southern California), and islands (leveed, because farming has caused substantial subsidence). Although the main ecosystem restoration goal is to enhance native species and reduce exotics (especially fishes), there is little natural habitat left and water demands preclude full hydrologic restoration. Restoration to historical conditions is not possible, but this is just the type of project that could include large experiments to create climate-buffered ecosystems. Some portion of the project could be designated as an experimental climate change reserve (*see* **Marshes, Anthropogenic Changes**, Volume 3).

## Grassland Ecosystems

Grasslands and prairies occur where conditions are wet enough for grasses but too dry for shrubs and trees (or too disturbed by fire or grazing). Because moisture and fire are key factors, grassland will be especially sensitive to changes in precipitation and in climate variability.

Grasslands and prairies have undergone extensive restoration over the last 65 years to recreate the aesthetic structure of prairies, to reintroduce fire to rehabilitate prairie remnants, and to create functioning ecosystems on abandoned farmland (Kline and Howell, 1987; Muller *et al.*, 1998). Restoring biodiversity requires continual planting and continual management of exotic invasions. Some species are notoriously difficult to maintain, while many invasive exotics are notoriously difficult to eradicate (Cottam, 1987; Kline and Howell, 1987). A good understanding of the ecology of the organisms involved and ongoing management, are needed to maintain restored habitats (Cottam, 1987). Difficulties are compounded when the original soil is badly degraded and a diverse seed bank absent. Success of restoration attempts of species-rich grasslands in France has been slowest and least predictable in areas where intensive agriculture or engineering processes have caused degradation of soil quality and loss of seed banks (Muller *et al.*, 1998).

In North America, prairie restoration tools include the use of herbicides, cultivation, and planting (Cottam, 1987; Kline and Howell, 1987). Labor intensive seed gathering and planting has been successful on small-scale plots (Cottam, 1987; Packard and Mutel, 1997). Larger scale efforts have adapted agricultural practices to the harvest and planting of native species.

Perhaps the most important lesson from work on grassland restoration is the usefulness of controlling fire and other disturbances as a means of altering or maintaining community composition. Many grassland communities depend on the periodic disturbance caused by fire to prevent woody species from invading (Packard and Mutel, 1997; Davison and Kindscher, 1999). The manipulation of disturbance in the form of fire or grazing can be used to restore native communities. Compared to many restoration activities, controlled burning or grazing can impact large areas of habitat, as will be needed to mitigate effects of global change.

Prairie restoration has focused almost exclusively on the establishment of plant communities, assuming that animals will find their way to suitable habitats (Kline and Howell, 1987). While many prairie specialist birds and small mammals do become established on restored prairies, many others will not do so without active intervention. For example, mound building ants play an important role in natural prairie ecosystems by cultivating the soil and providing open space where forbs can become established. Experience with the restored prairies at the University of Wisconsin Arboretum, US, found that even 50 years after plant communities were in place, ants were absent from much of the available habitat (Kline and Howell, 1987).

Because most restored prairies require continual maintenance (time and money), opportunities for mitigating the effects of climate change exist primarily at small spatial scales. These efforts could provide important source populations for the eventual natural spread of prairie species. Even relatively small patches of habitat may prove valuable in this role. For example, the 24 ha Curtis Prairie at the University of Wisconsin Arboretum, US, has maintained populations of about 170 native prairie plant species, even though it is surrounded by non-prairie habitats (Cottam, 1987). Manipulation of disturbance will be possible at larger scales, provided grassland species are already present (*see* **Temperate Grasslands**, Volume 2; **Tropical Savannas**, Volume 2).

## Forest Ecosystems

Forest ecosystems experience ongoing degradation and destruction through harvesting and clearing activities. Remaining fragments are subject to multiple stresses such as air pollution, invasive species, and new pests and pathogens. Changes in temperature and moisture will be a source of added stress, which will likely alter forest productivity and ecosystem functioning, while the distributions of most temperate zone trees will shift poleward, changing species composition (Intergovernmental Panel on Climate Change, 1996).

From the long history of tree planting, we know that many species can thrive when planted far outside their natural ranges (Ashby, 1987). Hence, some tree species should be able to survive despite climatic changes, while others should be able to grow when planted in favorable sites. While this is encouraging, forests also provide some of the clearest examples of the need to plant locally adapted populations or ecotypes (Ashby, 1987). The ease with which trees are established in artificial settings does not mean that planted populations will be self-sustaining or that other forest species of plants and animals will establish a functioning ecosystem (Ashby, 1987). One of the more difficult factors to account for in future restoration of forests will be the tight symbiosis between many plants and mycorrhizal fungi. Most plants depend on mycorrhizae for efficient uptake of water and nutrients, but the abilities of soil organisms to adapt to climate change are unknown. The ability of restoration to promote the rapid reestablishment of forest functioning will depend in large part on our ability to establish healthy populations of soil organisms (Haselwandter, 1997).

Longleaf pine (*Pinus palustris*) forest ecosystems provide a good case history for restoration of forest landscapes. Longleaf pine forests once covered 60% of the Southeastern US coastal plain, stretching from North Carolina to Texas. Longleaf pine forests host a surprising diversity of plant and animal species, including a large number of threatened and endangered species. Critical to the maintenance of these systems are periodic fires carried by understory plants that prevent invasion by deciduous oaks. Today, less than 10% of the original forests remain intact (Johnson and Gjerstad, 1998). This loss of a valuable ecosystem has led to an increasing interest in restoring longleaf pine communities by reintroducing fire and establishing populations of indigenous plants and animals. Some of the largest restoration projects ever undertaken are now in progress. The US Department of Defense military bases alone manage approximately 400 000 ha of longleaf-type vegetation (Johnson and Gjerstad, 1998).

Wiregrass (*Aristida* spp.) forms the dominant groundcover in most natural longleaf communities and provides fuel to carry fires (Means, 1997). Attempts to create a wiregrass understory in longleaf pine restorations provide an informative example of the limitations of restoration efforts. While wiregrass populations are present in many stands undergoing restoration, and plantings can be established with relative ease, these populations have typically failed to spread (Means, 1997; Seamon, 1998). Thus, while the species is present in the community, it fails to expand to serve a necessary function in the ecosystem (e.g., promoting the spread of beneficial fires).

Large-scale restoration of tropical forests has been initiated in both Latin America, Asia, and Australia. In Costa Rica, restoration efforts have focused on facilitating the natural recovery of ecosystems by promoting regeneration of forest trees and by attempting to control disturbance due to fire (Janzen, 1988; Holl, 1998). An alternative approach is to increase the ecological integrity of the large areas of tropical forest that have been converted to timber plantations. These areas may be improved, though not restored to a pristine state, by promoting the use of native species, planting mixtures of species, and altering landscape patterns of forests to provide buffers (Lamb, 1998). The experience gained through landscape-scale forest restorations is highly valuable for evaluating impacts and adaptation to global change, as well as our ability to compensate through restoration (*see* **Boreal Forest**, Volume 2; **Nitrogen Deposition on Forests**, Volume 2; **Temperate Coniferous Forests**, Volume 2; **Temperate Deciduous Forests**, Volume 2; **Rainforest**, Volume 2).

## BUILDING A CLIMATE CHANGE BUFFER INTO RESTORATION PROJECTS

Significant uncertainties about future climatic conditions exist. This is especially true at the relatively small scale of ecological processes and for precipitation and climatic variability. In order for current restoration efforts to prepare for the negative impacts of climate change, we need to understand the nature of climatic changes anticipated for a given site, and how land-management projects can best be planned to accommodate them. Significant advances in both climatic modeling and in understanding how ecosystems respond to changing climate will be needed before this is possible.

All sizes of restoration projects can build in some buffer against the negative aspects of climate change, but the greatest potential lies with the larger projects, such as the longleaf pine forest, Kissimmee River, Everglades, and San Francisco Bay Delta projects in the US. Large size restoration projects, like large preserves, can sustain more species and more genotypes. They can also support more effective exotic-species control programs, as they are more likely to have smaller perimeter/interior ratios, thus reducing chances for reinvasion. Finally, they would have the space needed to include well-planned translocation experiments.

Until more specific information is available, recommendations for buffering restoration sites are general, and they focus on increasing the resilience of communities in the face of environmental variability. These actions include:

1. Reintroduction of the full range of biodiversity (plants, animals, microbes) that was thought to occur prior to site degradation.
2. Maintenance of topographic heterogeneity; too many restoration sites have artificial landforms that are unnaturally smooth, due to modification by bulldozers.
3. Reintroduction of diverse gene pools. Growing plants from seed in preference to vegetative propagation. If the latter is necessary, ramets should be from multiple clones.
4. Eradication of exotic species and monitoring range expansion by new invasive species.
5. Allowing native species to remain on site. Some exceptions might be highly aggressive natives that might lower overall biodiversity.

6. Carefully monitored, experimental translocations of declining native species at restoration sites outside these species' natural range. This recommendation is consistent with biodiversity conservation efforts involving gardens, zoos, and seed banks but must be carefully planned to avoid adverse effects from introducing non-native species.

These suggestions are not specific to any climate scenario but are meant to increase the resilience of natural communities faced with a variety of anthropogenic stresses. Thus, they could be applied before reliable site-specific information on climate change becomes available.

## THE STATUS OF THE SCIENCE OF RESTORATION ECOLOGY

Several scientific challenges will need to be met before climate-buffered ecosystems can be designed.

1. Foremost, we will need reliable predictions of when, where, and how environmental conditions will change.
2. Next, we need to predict how species will respond to these changes, especially which species are most likely to go extinct as a result of climate change and which ecosystem functions will be impaired.
3. We need to be able to select appropriate tools to sustain biodiversity.
4. We need to understand the relationship between ecosystem structure and functioning. More attention will need to be directed towards the interactions among species that govern processes such as nutrient and water cycles, community stability, and the regulation of primary productivity.
5. We need to document the current status of reference sites. A major constraint on restoring historical habitats is our lack of knowledge of their structure and functioning. But looking ahead 50 to 150 years, we will have no excuse for not making detailed records of conditions such as species composition, productivity, and nutrient dynamics. With new technology, such as remote sensing, we can plot the precise locations of rare species populations and the geographical boundaries of species with various traits, for which we hypothesize likely expansions, compressions, range shifts, or no change. This will provide future biodiversity managers a basis for assessing change and considering restoration actions.

Climate change may affect critical components of the ecosystem that are yet unknown. The processes that go on below ground, for example, are at the frontier of ecology. The tight symbiosis between plants and mycorrhizal fungi has not received the attention it deserves. Owing to their poor dispersal and habitat specificity, mycorrhizae need to be added to highly degraded restoration sites (Haselwandter, 1997). While this is a common tool, we do not know the abilities of mycorrhizae and other soil organisms to adapt to climate change. Further complications may involve other microbes.

Research will need to be done before we can rely on restoration tools to ameliorate the effects of climate change at the large scale. Some encouragement comes from fire and water management, however, as both have been used to restore large expanses of habitats. The release of flood waters from Glen Canyon provides a positive model (Vaselaar, 1997), although the magnitude of planned flooding can never match historical extremes. We encourage replication of flooding experiments over time and large-scale experimentation in general.

## CONCLUSIONS

It is unlikely that restoration tools can be used to prevent negative impacts on ecosystems caused by climate change. However, global change can and should be considered when designing restoration projects. Detailed adaptation of ongoing ecological restorations is hampered by the uncertainties about the exact nature of future changes in climate and about ecosystem responses at specific sites. Until we have reliable, site-specific predictions, it is premature to suggest translocations into natural habitats, as we know too little about how the receiving site might be affected. A possible exception would be restoration sites designed to sustain rare plants and animals beyond their natural range (climate change reserves).

In general, restoration tools will be more useful after natural systems are noticeably degraded by climate change. If ecosystem degradation due to changing climate cannot be prevented, then ecological restoration may be one of the few strategies available to ameliorate the damage. Once again, restoration is unlikely to compensate fully for the loss of species and the reduction in ecosystem functioning that will likely result from significant climate change.

We expect that most efforts to ameliorate climate change will be of small spatial scale. Nevertheless, they will be important. Small patches of habitat provide refugia for sedentary species and sources of propagules and colonists for future natural expansion. Preservation of genetic diversity will offer greater potential for natural selection in the face of changing climate. The result, especially if the restoration site is large, should tend toward a climate-buffered ecosystem.

Progress in developing restoration tools provides both a reason for hope and sometimes a sobering lesson in the complex task that awaits us. Additional research advances will be needed to understand how ecosystems function and how humans can intervene in disturbed communities to promote diverse and healthy ecosystems.

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