Young, T.P. & K.J. Vaughn. 2011. Restoration. Pp. 594-597 in Encyclopedia of Invasive Introduced Species. D. Simberlof & M. Rejmanek (eds.), University of California Press.

allowed to trump the common good. And more effective control methods must be developed for a variety of the most invasive taxa.

SEE ALSO THE FOLLOWING ARTICLES

Biological Control, of Animals / Brown Treesnake / Burmese Python and Other Giant Constrictors / Pet Trade / Predators

FURTHER READING

Bomford, M., F. Kraus, S. Barry, and E. Lawrence. 2008. Determinants of establishment success in introduced reptiles and amphibians: A role for climate matching. *Biological Invasions* DOI 10.1007/s10530-008-9285-3.

Fritts, T.H., and G.H. Rodda. 1998. The role of introduced species in the degradation of island ecosystems: A case history of Guam. *Annual Review of Ecology and Systematics* 29: 113–140.

Kraus, F. 2009. *Alien Reptiles and Amphibians: A Scientific Compendium and Analysis.* Dordrecht, Netherlands: Springer Science and Business Media B.V.

Lever, C. 2001. *The Cane Toad: The History and Ecology of a Successful Colonist.* Otley, UK: Westbury Publishing.

Lever, C. 2003. *Naturalized Reptiles and Amphibians of the World.* New York: Oxford University Press.

Rodda, G.H., Y. Sawai, D. Chiszar, and H. Tanaka. 1999. Problem Snake Management: The Habu and Brown Treesnake. Ithaca, NY: Comstock Publishing.

Rodda, G.H., and C.L. Tyrrell. 2008. Introduced species that invade and species that thrive in town: Are these two groups cut from the same cloth? (327–341). *In* J.C. Mitchell, R.E. Jung-Brown, and B. Bartholomew, eds. *Urban Herpetology.* Herpetological Conservation, vol. 3. Salt Lake City, UT: Society for the Study of Amphibians and Reptiles.

RESTORATION

TRUMAN P. YOUNG AND KURT J. VAUGHN

University of California, Davis

Ecological restoration is defined by the Society for Ecological Restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed." Although this can mean the attempt to return the site to a "natural" or even wilderness condition, it also encompasses many kinds of ecosystem repair. Examples include revegetating mine tailings, returning forest to abandoned farmland, improving habitat for wildlife, and reestablishing historic fire or flood regimes. This work may require the elimination of degrading forces, preparation of sites, planting of appropriate species, and maintenance and monitoring of sites. At each of these stages, invasive species may impede successful restoration.

THE FACES OF RESTORATION

Ecological restoration can take many forms and appear under different names, depending on the objectives.

REVEGETATION: The reestablishment of vegetation on sites from which it has been lost, often with the primary goal of erosion control. This vegetation may or may not be specifically designed to replicate the indigenous vegetation of the site.

HABITAT ENHANCEMENT: Habitat "improvement," usually directed toward some desirable or threatened taxon (e.g., waterfowl). This may explicitly not include the return to predisturbance vegetation.

RECLAMATION: Originally used in the opposite sense of "reclaiming" land from nature for human use, now increasingly used to designate the more general idea of reclaiming land from a less desirable or degraded state to a more desirable state, which may include the reestablishment of natural vegetation.

REHABILITATION: The improvement of degraded land, which may include major restoration activities, but which may also include less intensive management techniques that favor shifts in certain aspects of the plant community, often with an extractive use in mind, such as ranching.

MITIGATION: The attempt to create a community type in a site where it may or may not have occurred before, done to balance the loss of a similar community or population elsewhere (such as from development).

REMEDIATION: Similar to mitigation, but with fewer legalistic overtones of one-for-one replacement. This can include the use of biodiversity, such as vegetation buffers, to increase ecosystem function or environmental quality (as in bioremediation).

GOALS

The list above comprises some of the diversity in the nature and goals of ecological restoration. Still, the most basic and general goal of restoration is the reestablishment of the predisturbed ecosystem. However, this objective may raise multiple questions when attempting to define measurable goals for restoration activities. For example, what is the proper reference state for restoration in systems with a long history of human management (e.g., meadows maintained by Native American fire practices in the Yosemite Valley, or by grazing practices in the Alps)?

Young, T.P. & K.J. Vaughn. 2011. Restoration. Pp. 594-597 in Encyclopedia of Invasive Introduced Species. D. Simberlof & M. Rejmanek (eds.), University of California Press.

More specific restoration goals may include objectives that are biological (e.g., reestablishment of native species or control of exotic species), hydrological (e.g., erosion control or reestablishment of inundation regime), geochemical (e.g., soil condition amelioration), social (e.g., reestablishment of recreation areas), or economic (e.g., reestablishment of ecosystem services). At some sites, the control of invasive species is an ultimate goal of restoration activities, but more often it is an important prerequisite for other, broader goals.

Biological goals at multiple scales can serve as quantifiable measures of restoration success. At the species and community level, such goals may include species richness (the number of species), species composition (relative abundance), guild structure (i.e., perennial grasses, nitrogen-fixers, annual forbs, woody shrubs), eradication or control of invasive species, and the restoration of threatened species and wildlife habitat.

Ecosystem-level functions may also be measurable goals of restoration. These include primary productivity, nutrient cycling and retention, carbon sequestration, hydrological function, and trophic integrity (mutualists, herbivores, carnivores). Ecosystem functions that more directly serve human needs are referred to as ecosystem services, and these include erosion control, runoff quality and quantity, pollination services, nutrient balance (soil fertility), extractive use (grazing forage, fisheries, timber), and aesthetic values (public use, tourism).

STAGES OF RESTORATION

Restoration activities comprise multiple stages (Table 1). The first stage in a restoration project is site assessment and project planning. This activity often includes the determination of restoration goals, which can include a combination of general and specific measurable objectives. Reference sites are often identified in this initial stage to represent quantifiable targets for measuring restoration success. Lists of appropriate, usually native species are generated, either for planting or as indicators of restoration success.

Restoration is unlikely to be successful unless the forces that caused the degradation of the system are identified and remediated. In some cases, the removal of degradative forces is sufficient to allow for the natural regeneration of the ecosystem. For example, the recovery of the eastern deciduous forest of the United States has proceeded well without intervention following the widespread abandonment of agriculture in the region in the nineteenth century. Other possible degradative forces include acidification, nutrient enrichment, soil compaction, mine tailings, topsoil removal, soil salinization, overgrazing, timber harvesting, and river damming and levees. The degradative force may also be the disruption of historic disturbance regimes, such as fire or flood regimes, and the reestablishment of these regimes on a landscape scale is often a broad goal of restoration activities.

TABLE 1
The Restoration Process

Stage 1: Site Assessment and Project Planning
Initial site evaluation/data collection
Selection of reference site/criteria
Determination of goals
Identification of degradative forces
Development of a restoration plan
Stage 2: Amelioration of Degradative Forces/Legacies
Remove disturbance (or reestablish disturbance regime)
Improve soil conditions
Restore hydrological function
Control invasive species
Stage 3: Active Planting
Site preparation
Seed collection/increase
Planting
Horticultural amendments (irrigation, mulch, shelters, fertilizer)
Stage 4: Maintenance/Monitoring
Maintain amendments as needed
Data collection/analysis
Adaptive management

NOTE: A simplified outline of the major stages and activities of a restoration project.

If the degradative forces leave behind a strong or long-lasting legacy, it may be necessary to prepare the site before natural regeneration can proceed. This can mean adding topsoil, ameliorating soil conditions (including impoverishing artificially enriched soils and waters), reconstituting hydrologic function, and providing weed control. Herbicide application, hand weeding, disking, tilling, fire, and grazing are all potential weed control techniques.

If, after this site preparation, natural regeneration is not possible, or if it occurs too slowly to meet project goals, then active planting of desirable species can be carried out. This may be preceded by seed collections from reference communities and by a process of seed increase, if natural seed sources are insufficient. Often seed or seedlings are commercially produced, ideally of local genotypes.

Plants may be seeded directly or planted as seedlings. Horticultural amendments such as irrigation, tree shelters, mulching, fertilizers, and mycorrhizal inocula may also be part of this planting effort.

Young, T.P. & K.J. Vaughn. 2011. Restoration. Pp. 594-597 in Encyclopedia of Invasive Introduced Species. D. Simberlof & M. Rejmanek (eds.), University of California Press.

Ideally, the project is then monitored to assess restoration success and to determine the need for appropriate adaptive management activities.

CONCEPTUAL ECOLOGICAL UNDERPINNINGS

Restoration ecology is the science that supplies research answers to questions concerning how best to achieve restoration goals and explores the ecological concepts underlying restoration. Restoration ecology draws from a wide range of environmental sciences, including agronomy, horticulture, hydrology, biogeochemistry, and ecology (as well as the social sciences; see below). Within ecology, important aspects of restoration include genetics; ecophysiology; and population, community, ecosystem, and landscape ecology.

Disturbance describes a change in environmental conditions that interferes with ecosystem structure or function. While disturbance is a natural process in all ecosystems, and the reestablishment of natural disturbance regimes is often a restoration goal in and of itself, severe or chronic anthropogenic disturbances may alter ecosystems beyond their capacity to naturally recover.

The concept of *succession* can be simplified as the tendency for disturbed communities to recover to their predisturbed state. There are systems where natural regeneration proceeds without intervention as long as propagule pressure from outside the disturbed area is sufficient, and the soils are relatively intact. Restoration in these cases may be either completely passive or may simply consist of jumpstarting or accelerating successional processes. *Assembly* theory suggests that multiple steady states may exist for a given site, determined in part by the order of arrival of its colonists. This theory suggests that the outcome of a restoration project may depend strongly on planting decisions, and that a site may not inevitably converge to a previous or desired state. *State-transition* models take the idea of assembly one step further and seek to outline not only the different possible states of a community but also the drivers determining transitions among these states, and they specifically include the activities of restoration. It is not uncommon for a highly invaded community structure to be one of these states.

Await new art.

FIGURE 1 Tamarisk (*Tamarix parviflora*), has severely invaded many riparian areas in the arid and semi-arid western United States. (A) Tamarisk (the reddish shrub in the foreground) in a restoration site in Utah. (B) Mechanical removal. (C) Vegetation immediately post-removal, with remnant native cottonwoods and space for recruitment of willows and more cottonwoods. (Photographs courtesy of the Bureau of Land Management, U.S. Department of the Interior.)

RESTORATION IN A SOCIOECONOMIC CONTEXT

Restoration is a human enterprise, and it takes place in a complex social context. The social complexity of a particular restoration project is partially a function of the spatial extent, intensity of intervention, number of landowners and managers potentially directly or indirectly affected, number of funding sources, presence of threatened species, and character of local, state, and federal laws and policies.

Restoration activities range from small, locally conceived and locally implemented "postage stamp" projects to regional-scale projects involving the coordination of hundreds of partners and multiple government agencies and nonprofits, and costing hundreds of millions of

Young, T.P. & K.J. Vaughn. 2011. Restoration. Pp. 594-597 in Encyclopedia of Invasive Introduced Species. D. Simberlof & M. Rejmanek (eds.), University of California Press.

dollars. (In the United States, such regional-scale projects include the Everglades, the California Bay delta, Lake Tahoe, and the Mississippi delta.)

Community involvement and volunteerism are hallmarks of ecological restoration. These efforts often include opportunities for assessing and informing public perceptions of natives, exotics, landscape, and "wilderness." Community participation in restoration activities can offer occasion for hands-on environmental education, as well as instill a sense of local land stewardship.

A substantial proportion of restoration projects are the result of legally mandated mitigation for development that has as its (largely unsubstantiated) underlying assumption that losses of species or habitats at one site can be recouped through restoration of another site.

INVASIVE SPECIES AND RESTORATION

In many sites, invasive species are one of the major sources of ecosystem degradation, and their control is often one of the primary goals of (and challenges to) restoration efforts. Invasive species can sometimes completely preempt successional regeneration, leading to the formation of a highly invaded stable community state. Invasive plant (and animal) species can be a degradative force in their own right, whose initial control is a prerequisite for restoration, and whose long-term control often requires the restoration of a native plant community that is resistant to further invasion (Fig. 1). In highly invaded sites like island ecosystems or the western grasslands of the United Sates, it has been said that there can be no successful restoration without effective weed control, and there can be no effective weed control without successful restoration. Conversely, in some ecosystems, nonnative species can be used to assist in restoration.

SEE ALSO THE FOLLOWING ARTICLES

Endangered and Threatened Species / Fire Regimes / Grasses and Forbs / Herbicides / Hydrology / Land Use / Mechanical Control / Succession

FURTHER READING

Baker, J.P. 2005. Vegetation conservation, management and restoration (309–331). In E. van der Maarel, ed. *Vegetation Ecology*. Malden, MA: Blackwell.

Ewel, J.J., and F.E. Putz. 2004. A place for alien species in ecosystem restoration. *Frontiers in Ecology and the Environment* 2: 354–360.

Falk, D.A., M.A. Palmer, and J.B. Zedler. 2006. *Foundations of Restoration Ecology*. Washington, DC: Island Press.

Hobbs, R.J. 2007. Setting effective and realistic restoration goals: Key directions for research. *Restoration Ecology* 15: 354–357.

Society for Ecological Restoration International. www.ser.org/

Van Andel, J., and J. Aronson. 2006. *Restoration Ecology*. Oxford: Blackwell.

Young, T.P., D.A. Petersen, and J.J. Clary. 2005. The ecology of restoration: Historical links, emerging issues, and unexplored realms. *Ecology Letters* 8: 662–673.

RINDERPEST

ANDY DOBSON
Princeton University

RICARDO M. HOLDO AND ROBERT D. HOLT
University of Florida

Rinderpest is a virus in the Morbillivirus family that causes disease in cattle; it created the largest pandemic ever recorded when it was introduced into East Africa in the early 1890s. Its invasion and spread caused the deaths of around 50 to 90 percent of cattle and wild artiodactyl species (wildebeest, buffalo, giraffe) in sub-Saharan Africa. The loss of hosts for tsetse flies created a human epidemic of sleeping sickness throughout sub-Saharan Africa. Rinderpest is closely related to human measles virus and canine distemper virus (of dogs); control was only achieved once methods used to develop a measles vaccine were applied to rinderpest in the early 1960s.

INTRODUCTION HISTORY IN AFRICA

Africa has been afflicted by many disasters in the relatively short period for which we have historical records: droughts, dictators, deforestation, swarms of locusts, and of course disease. Although over 20 million Africans are currently infected with the HIV virus that causes AIDS, and several thousand children die each day from malaria, arguably the worst disaster ever to have hit the African continent was the great rinderpest pandemic that started in 1889. In the ten years of its initial spread from the coast of Ethiopia in the Horn of the Africa until its arrival in Cape Town, it is estimated to have killed 80 to 90 percent of the cattle population and similar proportions of many artiodactyl species (wildebeest, giraffe, and particularly buffalo). These losses essentially devastated the protein supply for most of the human population of sub-Saharan Africa while simultaneously triggering an epidemic of sleeping sickness when starved tsetse flies switched to human hosts in the absence of their natural hosts.

Rinderpest provides detailed and important insights into the impacts that pathogens can have when they