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Restoration Is Preparation for the Future

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Returning a site or landscape to some historical condition is a long-standing objective in restoration ecology, but restoration ecology is by no means limited solely to the goal of returning an ecosystem to a prior condition. Restoration, done properly, can increase biodiversity, restore structure and connectivity, and enhance a variety of ecosystem services that may better position ecosystems to adapt to climate change, even where the primary intent of restoration may have had little to do with climate adaptation. In this discussion, we address how ecological restoration maintains biodiversity, structure, and function that prepare forests for an uncertain future, and we show how there is no inherent incompatibility between restoration and management for global change. Better education is needed about what restoration is and how it should be practiced. Some changes in the way that restoration is envisaged and implemented in an age of rapid global change are warranted, but calls for the replacement of ecological restoration by another paradigm are misguided.

Defining Ecological Restoration in an Age of Rapid Change

Restoration may seem like an outdated term with a narrow focus on past conditions that are not relevant to the future (Hart et al. 2015). The term restoration strongly implies return to a historical state, and early in the development of the field of restoration ecology there was an emphasis on returning ecosystems to their predisturbance condition (Allison 2012). In North America and Australia, this often meant a return to the conditions that existed before contemporary European land management practices. This emphasis neglected to account for land management practices, such as fire, carried out by preindustrial people to maintain historical ecosystems; more problematically, in highly modified regions such as most of Europe, the condition of ecosystems before modification by humans is difficult or impossible to determine. The focus of restoration thus shifted to a goal of restoring potential historical trajectories of the ecosystem that existed before disturbance, but which is now set on a new dynamic pathway of ecological and evolutionary change (Allison 2012). According to the most widely cited definition, developed by the Society for Ecology Restoration, restoration need not be limited to attempted recreations of historical conditions. Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged, transformed or entirely destroyed as the direct or indirect result of human activities" (Society for Ecological Restoration International, Science, and Policy Working Group [SER] 2004).

Restoration requires a reference condition as a waypoint, or trajectory target (Aronson et al. 1995, Egan and Howell 2001, Dey and Schweitzer 2014), and historical conditions can provide a template of natural ecosystem structure, composition, and function (Noss 1990, Morgan et al. 1994, Manley et al. 1995). Historical ecology represents our only empirical glimpse into the workings of ecological processes that occur at scales broader than the human lifespan (Wiens et al. 2012). We agree with Falk (1990) that "Restoration uses the past not as a goal but as a reference point for the future. If we seek to recreate the (ecosystems) of centuries past, it is not to turn back the evolutionary clock but to set it ticking again." The benefits of using history include (1) insight into patterns and mechanisms of temporal dynamics in ecosystems, (2) detection of human impacts on past and current ecosystem dynamics, thereby allowing the incorporation of knowledge into more sustainable management, (3) identification of highly stable or highly mutable ecosystems and ecosystem properties under climate change, (4) definition of parameters by which we might recognize "properly functioning" ecosystems, determine desired levels of ecosystem services, or understand when we have made an ecosystem more resilient to global change (Safford et al. 2012a, 2012b). Historical conditions provide a basis of comparison with current conditions, to indicate that transformation has occurred and to specify the nature of that transformation. However, identification of contemporary references may be more suitable than use of historical data when historical conditions have been modified for so long that it is not clear what premodified ecosystems looked like or where ecosystems have been degraded to the point of damaged or destroyed ecological functioning (Safford et al. 2012a).

Restoration and restoration projects that focus inflexibly on replication of the past will have diminishing relevance in the 21st century, except where historical conditions are demonstrably sustainable under projected future ranges of ecological variation. The realities of changing environmental baselines, such as climate change, introduced invasive species, land-use change, agricultural intensification, and pollution, combine to complicate the role of history in managing for the future and compel the restoration practitioner to consider the future as much as the past (Landres et al. 1999, Millar et al. 2007, Safford et al. 2012a, 2012b). Because strict historical fidelity is a near impossibility in the contemporary world (Harris et al. 2006, Cole et al. 2010, Stephenson et al. 2010), restoration is best deemed successful when an ecosystem

> will sustain itself structurally and functionally,…demonstrate resilience to normal ranges of environmental stress and disturbance, (and) interact with contiguous ecosystems in terms of biotic and abiotic flows and cultural interactions. (SER 2004)

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> restored ecosystem will not necessarily recover its former state, since contemporary constraints and conditions may cause it to develop along an altered trajectory. (SER 2004)

Attributes of restored ecosystems may include species composition that predominantly is indigenous and an environment that supports reproducing populations of these species. Such an ecosystem is as resistant (i.e., able to maintain structure, composition, and function) and resilient (i.e., able to regain structure and composition within limits and function after damage or during environmental change) to stress to the same extent as the reference ecosystem (SER 2004). Sustainable restorations will have repaired fundamental ecosystem processes (hydrology, nutrient cycling, soil-forming processes, natural disturbance regimes, predator-prey relationships, and pollinator-plant interactions) that are then free to respond resiliently to changing conditions. In a rapidly changing world, attainment of even process-based objectives may be difficult. For example, historically "normal ranges" of ecosystem variation may no longer encompass the impacts of modern or future stress or disturbance, areas targeted for restoration may be isolated by human land uses, and sustenance of ecosystem structure and function may require periodic or constant human intervention (Harris et al. 2006, Millar et al. 2007, Wiens et al. 2012).

Properly Done, Restoration Is Preparation for the Future

Although the rapidity of global change may require refocusing strategic objectives in some restoration efforts, the viability of most established restoration tactics and practices is not at risk. The reality is that we cannot faithfully recreate historical conditions on the ground, but the functional, structural, and compositional goals of many projects with historical target conditions are perfectly compatible with global change adaptation. In ecosystem management focused on vulnerability to global change, we try to anticipate and mitigate potential threats so that ecosystems are not degraded to the extent that they require intensive restoration. Principles for adaptation of ecosystems to climate change include the following: sustain function, structure, and composition (i.e., diversity); reduce impacts of other stressors and severe disturbance; and maintain or create refugia, redundancy, and connectivity (Noss 2001, Millar et al. 2007, Heller and Zavaleta 2009, Janowiak et al. 2014). Recommendations include favoring native taxa that are better adapted to future conditions, such as those with wide tolerances that are drought- and heat-tolerant; revegetate after disturbance; maintain seed and seedlings; and control invasive species (Janowiak et al. 2014). Where ecosystem degradation has occurred, restoration projects also seek to increase resistance and resilience by maintaining diversity, ecosystem services, and connectivity (SER 2004, Clewell and Aronson 2013).

Restoration and management for the future are not dichotomous or mutually exclusive objectives. As long as a restoration project remains aligned with the principles outlined above, it is likely to serve purposes associated not only with enhanced ecological value but also with resilience to global change while providing for social well-being. This can be the case even when the project seeks to restore historical conditions. A meta-analysis by Rey Benayas et al. (2009) showed that ecological restoration increased biodiversity and ecosystem services, regardless of the actual intent of the restoration project. Wiens et al. (2012), Clewell and Aronson (2013), Murcia et al. (2014), and other authors refer to multiple examples of "traditional" restoration projects where ecosystem conditions were improved, historical trajectories reestablished, and resilience to stress or disturbance enhanced.

As restoration scientists, we are acquainted with and involved in a variety of restoration projects that have the future firmly in mind. Clewell and Aronson (2013) observed that although the past may serve as a guide, "we invariably restore ecosystems to the future." Restoration of wetlands and watersheds degraded or destroyed by human land uses is often carried out to mitigate the risk of flooding and catastrophic soil loss, along with providing a variety of other ecosystem services including increased biodiversity and carbon storage (Groffman et al. 2014). Successful stream restoration creates hydrological, geomorphological, and ecological conditions that result in resilient and (ideally) sustainable streams that can recover from rapid change, such as flooding or dewatering, and stress, such as increased water temperatures, and are better positioned to persist through uncertain future conditions (Kauffman et al. 1997, Palmer et al. 2005). In North America, many areas of historical open hardwood and conifer woodlands and savannas have been transformed by human management and altered disturbance regimes (e.g., fire exclusion) to densely stocked forests of more shade-tolerant but less fire-tolerant species. These shifts in ecosystem structure and composition from historical conditions often have cascading negative ecosystem consequences in declining quality and loss of wildlife habitat and local to regional extinctions of species (Brawn et al. 2001, McShea et al. 2007, Noss 2013, Kendrick and Thompson 2013, Reidy et al. 2014, Starbuck et al. 2015). Restoration in these ecosystems favors oak and pine species that have survived a wide range of historical climates, including the Medieval Warm Period, the Holocene Climatic Optimum (Hypsithermal period), and drought during the Little Ice Age, which indicates that they may be better adapted to survive warmer, droughtier conditions in the future than the species that have replaced them (Allen et al. 2002, Hanberry et al. 2014).

Updating Ecological Restoration

Many ecosystems today are highly modified in structure, composition, and function and are becoming increasingly so. During the past 100 years, there has been more rapid climate change than during the previous 100 years and the rate of change is accelerating (Lawler et al. 2010). Coupled with rapid climate change are increased rates of land cover change and conversion (e.g., urbanization and habitat fragmentation), agricultural intensification, spread of invasive species, and increased rates of resource extraction (Noss 2001, Sanderson et al. 2002). These sorts of anthropogenic changes are creating "novel" ecosystems with combinations of species and physical conditions unlike any that have existed before (Hobbs et al. 2006). The apparent ubiquity of novel ecosystems and an unknown future are fueling calls for a deconstruction of the restoration paradigm and its replacement with "intervention ecology" (Hobbs et al. 2011, Marris 2013, Hart et al. 2015). Nevertheless, every ecosystem in the history of the world has been novel at some time, humans have affected ecosystems for millennia, climates and atmospheric chemistry have always fluctuated, and "invasion" is simply a (rapid and undesired) biogeographic movement. What is perhaps novel (with the exception of mass extinction events recorded in the fossil record) is the rapidity, amplitude, and extent of these changes.

We caution against progressing radically away from the established norms of restoration ecology and blindly embracing novel ecosystems as a management goal, but we also stress wider and more flexible management than a narrow focus on returning ecosystems to the precise conditions of some historical time period. The field of restoration ecology is firmly established, and rather than changing terminology and taking off in an entirely new direction, it may be more useful to emphasize that restoration maintains biodiversity and ecosystem function, structure, and processes, thereby positioning ecosystems well for an uncertain future. Although we do not believe that global change necessitates a major overhaul in the modern ecological restoration paradigm, we do see some room for improvement and balance in the way that ecological restoration is envisioned and implemented.

1. Ecological restoration should be more proactive than reactive. Moving forward, the restoration framework should stress active and adaptive management to meet emerging issues instead of intervention after transformation or degradation of ecosystems. Management for prevention of transformation or degradation may be a better use of resources and result in more desirable outcomes than restoration after continued ecosystem degradation. Adaptive management has a long history in management theory, but rarely have long-term monitoring and restoration been coupled.
2. Restoration is not a one-time event but requires long-term commitment to reset trajectories to a waypoint that leads to desired future conditions bounded by ecological and social determinants. Ecological restoration should have a greater focus on restoring ecological functions and disturbance processes, which will maintain composition and structure. Restoration should strive to result in resilient ecosystems that are free to change with climate and future conditions in the same way that undegraded ecosystems do, thus maintaining an element of randomness (Higgs and Hobbs 2010).
3. Ecological restoration should not be obsessed with historical fidelity. Historical or contemporary reference conditions provide waypoints, not endpoints. The historical range of variation is a valuable baseline against which to assess the degree of alteration for understanding the mechanics of global change in ecosystems and for evaluating potential management goals and options for recovery of biodiversity and ecosystem services (Safford et al. 2012a, 2012b). Treatments and outcomes should be flexible based on what is present on the ground. That is, prairie and pine restoration can include open oak savannas, whereas restoration for certain ecosystems can tolerate rare remnants of another species or ecosystem type.
4. Ecological restoration effort and intent should vary along the gradient of ecosystem degradation. Modern landscapes are patchworks of ecosystems and ecosystem remnants that vary in their levels of naturalness. Hobbs et al. (2014) categorize these into "historical, hybrid, and novel" ecosystems and make the case that management interventions in such landscapes will depend on the degree of alteration, likelihood of restoration success, and landscape context. In some cases it may be possible to return a transformed ecosystem to its predisturbance state, but in many cases that may be impossible or impractical given the degree of ecosystem change and socioeconomic factors, among other things (Hobbs et al. 2009). If reversibility is not a practical option, then novel ecosystems still can be restored, prioritizing fundamental ecosystem processes (hydrology, nutrient cycling, soil formation, natural disturbances, and others) to provide greater native biodiversity and ecosystem services than they provide now (Hobbs et al. 2014), even if the result is not an historically faithful rendition of the original ecosystem.
5. It is important to differentiate restoration objectives for degraded ecosystems that have compromised ecosystem functions and services from those for transformed ecosystems that provide different ecosystem services along with alternative composition, structure, and function. In many regions, because of a lack of historical disturbances (e.g., frequent fire) or the presence of novel stressors, there have been regime shifts or a turnover in ecosystems from one functioning state to another, for example, from open savannas and woodlands to closed forests. In such cases, ecosystems that once occurred across landscapes are now present only as local remnants (Suding et al. 2004, Hanberry et al. 2014). Many species associated with these now-rare ecosystems are declining (Hunter et al. 2001, Gilliam 2007, Noss 2013); individual species do matter for this type of restoration, and species, in general, are much more sensitive to extinction than processes. A historical view is necessary to recognize that these historical ecosystems have withstood the test of past climate change and possess genetic diversity and traits related to exposure (e.g., heat, solar radiation, or drought) to endure future climate change and provide unique functions (Wiens et al. 2012). When both alternative states provide ecosystem services, restoration of transformed ecosystems is not about quantitative accounting of the best gains in ecosystem services but about supporting the historical state until future conditions might favor it again.
6. The needs and wants of society will lead to both restoration and restrictions on restoration based on tradeoffs in costs and benefits. Human society has modified landscapes to fit needs and/or conveniences, and some processes, such as fire, will not be acceptable in all restoration projects. We need a better understanding of what we can sacrifice and what we will not tolerate.

Conclusions

We disagree that restoration is about the past, from the past, and best left in the past. Restoration in a modern sense seeks to maintain or recover biodiversity and ecosystem composition, structure, function, and services to position ecosystems for an uncertain future rather than returning ecosystems to static past conditions. Restoration, redefined to be comprehensive and flexible, is more about the future than the past (SER 2004, Clewell and Aronson 2013). A possible danger of redefining restoration is that the concept will swing too far from restoring rare and immensely valuable historical ecosystems into cost-benefit considerations to maximize biodiversity, regardless of identity, or to provide the greatest amount of ecosystem services from degraded ecosystems, independent of considerations of species identity or historical trajectories. Completely abandoning historical ecosystems in favor of repairing processes may be an acceptable management plan for highly degraded novel ecosystems (such as intensively grazed lands, islands with nonnative species, and suburban development) (Hobbs et al. 2014), but restoration of transformed yet functioning ecosystems remains essential, based on the value of supporting ecosystems and associated species that have become rare and may face extinction. Species can become rare and extinct in transformed but well-functioning ecosystems, and we slide down a slippery slope to accept extinctions as long as ecosystem processes and services still remain.

Restoration efforts on the ground have galvanized public interest and attracted major public and private funding, restoration ecology is one of the fastest growing disciplines in the field of applied ecology, and federal resource management agencies (e.g., the USDA Forest Service) and major nongovernmental organizations (e.g., The Nature Conservancy) are committed to its widespread implementation. Moreover, restoration is not just about restoring ecosystems or recovering populations of species. It is vital that restoration help restore the human-nature relationship at a time when people are increasingly removed from the natural world and illiterate about biodiversity and ecological and evolutionary processes (Jordan 2003, Noss 2013). If the general public does not value the natural world, then society is not likely to provide the social, financial, and volunteer support necessary to carry out and maintain ecological restorations on a large scale anywhere. It is past time to turn human alienation from nature around; doing so provides our only hope of halting the extinction crisis and sustaining functional ecosystems into the future.

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RESPONSE

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Has Forest Restoration Been Freed from the Bonds of History?

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The focus of ecological restoration has evolved, and the scope has broadened considerably over the last several decades. Early restoration efforts were largely regulatory in nature and focused on reestablishing plant cover on surface mines and other reclaimed lands (Wagner et al. 2000). Forest restoration as a management goal arose in the 1990s after the realization of the negative ecological consequences of anthropogenically altered disturbance regimes, fire suppression in specific. Nascent forest restoration projects were focused on mimicking the outcomes of historical periodic wildfires to mitigate the effects of fire suppression (Covington et al. 1997). Thus, the historical range of variation (HRV) concept was critical in defining forest restoration goals. Forest restoration projects have since expanded beyond addressing the effects of fire suppression to include creation of compositional and structural forest characteristics and disturbance regimes hypothesized to be representative of historical conditions. The HRV has provided the basis for identifying the desired future conditions in forest restoration plans, and the common theme in forest restoration has been to return forest ecosystems to predegraded conditions. As the scope of forest restoration has expanded, the definition has become increasingly nebulous. What, then, is contemporary forest restoration?

Hanberry et al. (2015) did not provide a comprehensive definition of their version of forest restoration but did include more than 15 descriptions of restoration. Many descriptions did not include mention of recreating past patterns or processes and several explicitly stated that restoring was not a goal of restoration. The authors suggested that restoration has moved beyond efforts to recreate conditions within a site's HRV and is now focused on managing for uncertain futures through the principles of resiliency and climate change adaptation. Although we agree with these management concepts (see Hart et al. 2015), we contend that if forest restoration is no longer primarily concerned with the recovery of ecosystem conditions within the HRV, the term "restoration" is a misnomer. Incorporating resiliency in management goals is wise forest stewardship, but labeling this objective as restoration can lead to a disconnect between restoration scientists and forest managers (i.e., those directly involved with forest restoration). In our experiences, many managers are working from a paradigm and the associated regulatory guidelines that define forest restoration as the recovery of historical patterns and processes that existed before degradation, a definition that does not explicitly include enhancing forest resiliency, biodiversity, or complexity. Given this disconnect between restoration scientists and forest managers, a discussion on what is and what is not forest restoration is warranted and may lead to clearer and more widely accepted definitions that can be translated into guidelines specified in forest management plans (Stanturf et al. 2014).

The descriptions provided by Hanberry et al. (2015) suggest that restoration is no longer about the recovery of predegraded forest patterns and processes. Instead, the goal of restoration is now to recover the "resiliency" hypothesized to be characteristic of prede-

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