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OPINION ARTICLE

What's wrong with novel ecosystems, really?

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The novel ecosystems concept has gained much traction in the restoration community. It has also drawn the ire of several prominent ecologists and is the focus of an ongoing debate. We consider three key aspects of this debate: irreversible thresholds, non-native species, and the hybrid state. Irreversible thresholds have been acknowledged in restoration for years, but predicting when a threshold will be crossed and the degree of reversibility is problematic. Oftentimes reversibility is a function of multiple factors, such as cost and public support. In this sense, a novel ecosystem is not an alternate state but a decision. The need for pragmatism regarding control of non-natives has also long been recognized in restoration circles. Proponents of the novel ecosystem idea adopt this pragmatism by recommending that management decisions be based on impacts conferred by species in altered ecosystems, regardless of their origin. The concept of a hybrid state has proven difficult to operationalize. We suggest that rather than trying to identify the boundary between hybrid and novel states, ecosystems exist on a gradient of alteration. We offer a decision tree for restoration action that integrates aspects of novel ecosystems with other perspectives in modern restoration ecology. We conclude that the idea of novel ecosystems, though not perfect, deserves a place under the "big tent" of restoration that includes efforts to return fully to a reference state, as well as strategies for reinstating lost ecological processes and enhancing ecosystem services in transformed landscapes where such a return is deemed infeasible.

Key words: decision tree, hybrid ecosystem, non-native species, regime shift, threshold

Conceptual Implications

- Several of the core ideas embodied in the controversial novel ecosystems concept are already well established in restoration thinking and practice.
- A realistic and useful decision framework will recognize that ecosystems exist on a gradient of alteration, restoration endpoints exist along a similar gradient and are rooted in both ecological and socioeconomic factors, and novel elements may have value.
- To avoid confusion among practitioners and misguided outcomes, novel ecosystems should be addressed explicitly in national natural resource management and restoration policies, and the Society for Ecological Restoration is the logical choice to take a leadership role in such efforts.

Introduction

In the last decade of the twentieth century, the renowned conservation biologist E.O. Wilson (1992) observed that the next century would be the era of restoration in ecology. More than two decades later, an impressive and growing list of restoration projects has been implemented worldwide (Clewell & Aronson 2013; Woodworth 2013), and the science of restoration ecology is reaching new heights in terms of journal articles, books, and attendance at national and international meetings. Clearly, restoration has come a long way since its genesis in the 1930s (Jordan & Lubick 2011).

Yet at a time when restoration has become essential to the conservation toolbox, the discipline (or at least its scientific arm) appears to be splintering into different camps. Nowhere is this more evident than in the ongoing debate on novel ecosystems. On the one hand, the concept of novel ecosystems has gained much traction since the term was coined (Chapin & Starfield 1997), especially following the publication of a series of articles by Richard Hobbs and his colleagues (Hobbs et al. 2006, 2009; Seastedt et al. 2008). Since 2006, "novel ecosystems" has been referenced in hundreds of peer-reviewed articles and has been the focus of numerous symposia and a recent book (Hobbs et al. 2013*a*). At the same time, the novel ecosystems framework has raised the ire of a host of prominent figures in the restoration and conservation communities, resulting in heated and sometimes acrimonious exchanges in journals (Hobbs et al. 2014; Murcia et al. 2014), at professional meetings (Woodworth 2013), and on the Web (Simberloff et al. 2015).

Challenging existing paradigms drives innovation and progress in science. Questioning new ideas invites reflection and revision. But debates become counter-productive to the extent that they foster entrenched positions and fragment the science and management communities at a time when all hands

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are needed on deck. Resolving such debates will require not only clear articulation of differences but also highlighting areas of agreement. Toward this end, we first critically examine several key points in the debate about novel ecosystems. We next offer a decision tree to guide restoration actions that integrates some, but not all, aspects of the novel ecosystems framework with other perspectives represented in modern restoration ecology. We conclude that the idea of novel ecosystems, though not perfect, deserves a place under the "big tent" of modern restoration concepts.

What's the Controversy?

When first brought to the attention of the restoration and conservation communities, novel ecosystems were defined by two characteristics—novel combinations of species that could alter ecosystem processes and a genesis in human action (Hobbs et al. 2006). Some critics find fault with the term "novel," suggesting that adjectives such as "transformed" (Aronson et al. 2014) or "emerging" (Clewell & Aronson 2013) would be more appropriate. Perhaps, but no matter. The "novel" genie is out of the bottle, like it or not, as the phrase "novel ecosystem(s)" has been cited more than 275 times in journal articles since 2006—articles that did not include Richard Hobbs as an author.

As the term has gained acceptance, the definition has changed somewhat. In a recent iteration, a novel ecosystem is defined as "a system of abiotic, biotic, and social components (and their interactions) that, by virtue of human influence, differs from those that prevailed historically, having a tendency to self-organize and manifest novel qualities without intensive human management" (Hobbs et al. 2013*b*). Novel ecosystems are held distinct from emerging or no-analog ecosystems of the past by virtue of a more rapid and accelerating pace of environmental change in the world today (Hobbs et al. 2009). In this conception, novel ecosystems are also distinguished from hybrid systems, or those containing a mix of historical and novel characteristics. The latter can more readily be restored to a historical state, whereas novel ecosystems have crossed a threshold beyond which restoration is, at best, very unlikely (Hobbs et al. 2013*b*). The implications of ecological thresholds for efforts to restore novel ecosystems, however, are a central point of contention (Murcia et al. 2014).

Thresholds

Critics of novel ecosystems do not deny that ecological thresholds exist, or that ecosystems may experience regime shifts. Rather, they dispute the existence of "irreversible" thresholds separating hybrid from novel ecosystems, beyond which restoration is impossible (Aronson et al. 2014; Murcia et al. 2014). Interestingly, the word "irreversible" does not appear in the most commonly cited descriptions of the framework (Hobbs et al. 2006, 2009, 2013*b*). Instead, in these articles the thresholds that define novel ecosystems are described as "difficult to reverse" (Hobbs et al. 2006) and "reversible only with the input of significant management resources and effort" (Hobbs et al. 2009). Even so, is the notion of ecologically irreversible thresholds really so outrageous?

Apparently not, even to some of the most vocal critics of the novel ecosystem framework. The Society of Ecological Restoration International's *Guidelines for Developing and Managing Ecological Restoration Projects* (Clewell et al. 2005) describes one context for restoration as "transformation of an ecosystem that was *irreversibly* altered" to another kind of ecosystem from the bioregion. Elsewhere, Aronson and his colleagues note that "in heavily modified systems, which have crossed one or more thresholds of *irreversibility*, restoration of the preexisting species inventory may no longer be feasible" (Aronson et al. 2007, p 6–7). Along these same lines, Clewell (2009, p 244) allows that restoration project goals may need to "anticipate a future state on account of *irreversible* changes in environmental conditions such as climate change, sea level rise, or *irreversible* anthropogenic changes to the environment."

As climate change proceeds, the list of systems that cross irreversible thresholds will undoubtedly grow. These cases will lengthen what is already a lamentably long list of regime shifts driven by human action that for all intents and purposes appear irreversible. In terrestrial systems, such transitions are often precipitated by wholesale changes in vegetative cover. This might involve the loss of foundation species such as eastern hemlock (*Tsuga canadensis*) and American chestnut (*Castanea dentata*) in the forests of eastern North America (Ellison et al. 2005), or the extensive loss of vegetation cover, a primary expression of desertification. Vegetation loss is followed by the creation of positive feedbacks that substantially alter the physical environment, via soil loss for example, that stabilize the system in a new state (D'Odorico et al. 2013). It is difficult to imagine these extensive ecosystems being restored to their former states over any meaningful spatial scale or time frame. It is equally difficult to predict precisely when a threshold will be crossed, and the degree to which the transition will be irreversible. On this, both critics and proponents of the novel ecosystem concept agree (Hobbs et al. 2009; Murcia et al. 2014).

Further complicating this aspect of the novel ecosystems framework are examples of highly altered systems where, with substantial management input, historical ecosystem elements have been recovered (Ewel 2013). This suggests that the degree to which thresholds are reversible may often depend on considerations such as cost, public support, and the like. In this sense, "novel" is not an alternate state of the system, but a decision. Hence, assessments of what constitutes a novel ecosystem need to be made on a case-by-case basis (Murcia et al. 2014). For example, the barriers to restoration of oak woodlands that have been highly degraded by invasive understory vegetation in Chicago's forest preserves may be surmountable. There, legions of motivated volunteers, well-funded natural resource agencies, and a wealth of local expertise serve to enable broad-scale removal of exotic shrubs and ground cover (Cleeton & Miller 2014). Similar woodlands on farmsteads in rural Illinois, where broad support for restoration is lacking, are for all intents and purposes novel ecosystems managed for the ecosystem services they continue to provide.

Non-native Species

The novel ecosystem debate is amplified by a related and equally contentious issue, the merits of non-native species (Davis et al. 2011; Simberloff 2011). Non-native species are considered in the novel ecosystem framework in several ways. First, human activities have facilitated the spread of non-natives, thus giving rise to novel combinations of plant and animal species, and hence novel ecosystems (Hobbs et al. 2006, 2009). Second, it may not be possible to remove all non-native species from a given system, especially given scarce management resources, thus necessitating prioritization schemes that target removal of species that are especially pernicious (Hobbs et al. 2006, 2009; Davis et al. 2011). Even if removal of all introduced species is possible, is it desirable? Not only might their removal facilitate invasions by other non-native species (Zaveleta et al. 2001; Seastedt et al. 2008; Gardener 2013), but non-native species may be considered desirable elements that perform valuable functions in some ecosystems (Hobbs et al. 2006, 2009, 2014; Belnap et al. 2012).

Detractors of the novel ecosystem framework appear to be on board with much of this. There is support for prioritization of non-native species control on the basis of their impacts, and recognition of the valuable roles that introduced species perform in ecosystems (Simberloff 2011). On the other hand, some of these same individuals assert that postponing management action until an impact is demonstrated is ill advised, given lag effects, and other unknowns (Simberloff 2015).

The potential for unforeseen adverse effects of non-native species to become manifest years or even decades post-introduction argues for a measure of vigilance. The need for pragmatism in decisions regarding control of non-natives and their ecological value has long been recognized in restoration circles (SERI Science & Policy Working Group 2004). In fact, the SERI Primer supports the use of non-indigenous plants in restoration under some conditions (SERI Science & Policy Working Group 2004). Similarly, consideration of non-natives by proponents of the novel ecosystem concept tend to focus not on intentional introduction but rather on recognizing positive impacts conferred by species in altered ecosystems, regardless of their origin (Hobbs et al. 2009; Jones 2013; Richardson & Gaertner 2013; Muñoz-Erickson et al. 2014).

Hybrid Ecosystems

Another aspect of the novel ecosystem framework that some critics find troublesome has to do with so-called hybrid ecosystems. As with "novel," they disparage the term "hybrid" as jargon that is misleading and confusing (Clewell & Aronson 2013; Aronson et al. 2014).

And it is confusing. In an attempt to operationalize the novel ecosystem concept by Hulvey et al. (2013), it seems that the main difference between hybrid and novel ecosystems is that with a novel system, reverting to a historical state is very unlikely, whereas with a hybrid system it is less unlikely, but not always certain. So it depends, and this is frustrating to those who seek clear delineation between historic, hybrid, and novel states—even more so to those trying to identify these states *a priori*.

Perhaps for these reasons, few of the contributors to the recent compendium *Novel Ecosystems* (Hobbs et al. 2013*a*, 2013*b*) explicitly consider hybrid ecosystems. Most tend to ignore this aspect of the framework completely (but see Hulvey et al. 2013; Tognetti 2013). We reviewed articles published in 2014 and through the first half of 2015 that focus on novel ecosystems ($n = 79$). None of these authors operationalize the hybrid state, and again, many do not consider it at all, simply focusing on their system's novel elements, however pervasive these elements may be.

A Novel Alternative

Rather than being a radical and potentially dangerous new idea, we suggest that the novel ecosystems concept connects to and complements existing restoration frameworks. To illustrate this point, we propose a decision tree that incorporates the novel ecosystem concept as a means to choose among a suite of well-known restoration alternatives (Fig. 1).

If an ecosystem is deemed to be relatively free of adverse human impacts, then conservation could be regarded as an imperative. If it is altered to an appreciable degree, then we must decide whether or not to attempt restoration of the historical state. If we decide not to—as we often do for a variety of reasons including feasibility or finances—we may choose to sustain and manage the novel ecosystem. For example, Rogers and Chown (2014) examined the effects of non-native, invasive acacia species on bird communities in the Western Cape of South Africa, where acacias have invaded over 2.7 million hectares. Their results indicate that acacia-dominated stands support diverse communities of native birds and could be managed, via thinning or timber cutting, to enhance avian species diversity. Alternatively, we can choose to "engineer" a novel ecosystem toward goals that are not necessarily dictated by historical fidelity but by specific ecosystem services, such as water storage or sediment and N removal in urban streams (Palmer et al. 2014).

If recovery to a historical state is deemed feasible and restoration undertaken, the effort may be largely successful (Jones & Schmitz 2009; Martin & Kirkman 2009) or only partially so. The latter may result in a novel or hybrid ecosystem, as is the case in attempts to recover native perennial grasses in the Chihuahuan Desert following the removal of encroaching shrubs (Coffman et al. 2014). The "novel ecosystem" concept simply puts a name to a class of ecosystem that is not historical but without the heavy baggage of the term "degraded"; the name allows for managers to define and justify alternative goals when restoration is not practical or desirable. Even without use of the term, management of novel ecosystems already is, and has been, part of restoration thinking and practice.

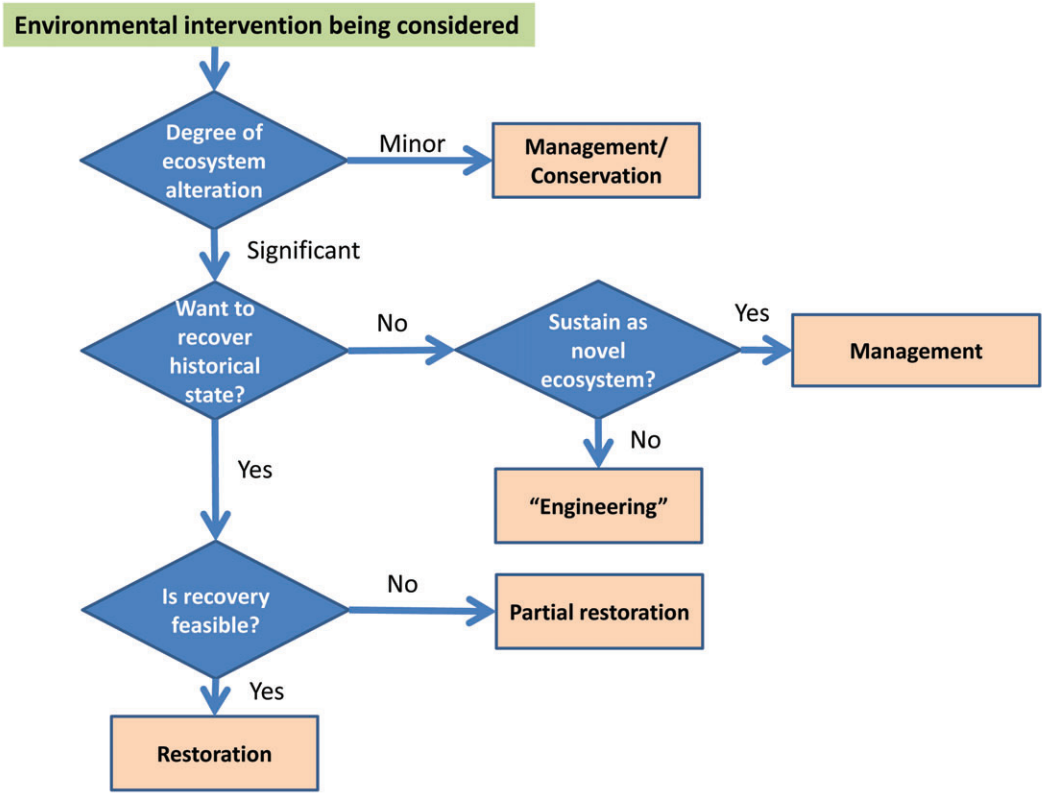

Figure 1. Decision tree integrating elements of the novel ecosystem framework with a suite of restoration alternatives.

A Path Forward

The proponents of the novel ecosystem concept have done a great service by providing a vision of ecosystems that does not equate "altered" with "degraded." In other words, there may indeed be value in the novel aspects of a given ecosystem and this value should be cultivated by land managers and measured by scientists. The merit of this perspective is enhanced to the extent that we experience departures from the historic range of variability in various systems, which seems likely. However, we find the novel ecosystem framework to be problematic in its emphasis on irreversible thresholds and hybrid versus novel states. It may be more useful to characterize ecosystems in terms of a gradient of alteration. The point at which full restoration to a reference system is abandoned is not simply an observable ecosystem state, but rather a decision based on multiple factors.

There is concern that buy-in to the novel ecosystem concept may cause land managers to forgo restoration when it is feasible (Aronson et al. 2014). To the extent that restoration is focused exclusively on fidelity to historical conditions, such concern may be warranted. A recent survey of conservation experts found that nearly 70% questioned the relevance of historical baselines to guide conservation and restoration actions, given global change (Hagerman & Satterfield 2014). Yet restoration is frequently defined in terms that go beyond strict adherence to historical references.

The *SERI Guidelines for Developing and Managing Ecological Restoration Projects* (Clewell et al. 2005) describes several contexts for restoration that depart from historical targets. These include *transformation*, as noted above, and *substitution* of a replacement ecosystem either because the environment would no longer support a historic ecosystem, or because no reference system exists to serve as a model for restoration. The authors note that such replacement ecosystems "… might include novel combinations of indigenous species" (Clewell et al. 2005, p 5). Similarly, Aronson et al. (2007) suggest a focus on restoring ecosystem function in heavily modified systems where historical species assemblages are not viable restoration targets.

Embracing a broader definition of restoration (Clewell et al. 2005; Aronson et al. 2007, 2014) helps to ensure a place at the table for this discipline as land managers grapple with increasingly uncertain environmental conditions and unprecedented challenges. Under such circumstances, it makes sense to envision restoration as a "big tent" that includes not only efforts to return fully to a reference state (Palmer & Ruhl 2015) but also strategies for reinstating lost ecological processes and enhancing ecosystem services in transformed landscapes where such a return is not deemed feasible.

Woodworth (2013) notes that individuals on both sides of the novel ecosystem debate value biodiversity conservation, recognize the dynamic nature of ecosystems and the futility of establishing restoration targets that are frozen in time, and understand that ecological restoration is ultimately a matter of human values. What is really needed at this point is clear articulation of best practices and related policies for land management agencies (Palmer & Ruhl 2015), and also clear statements of restoration goals and strategies for attaining them on any given project. Such an effort could be led by the Society for Ecological Restoration in conjunction with environmental ministries or agencies in various countries. Burying the novel ecosystem concept, however, is no longer an option.

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