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STRATEGIC ISSUES ARTICLE

Novel and designed ecosystems

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Growing attention to novel and designed ecosystems, and the confusion that follows from the overlap of these distinct ecosystem approaches, risks a loss of focus on ecological values at the core of restoration ecology. Novel ecosystems originate in ecosystems that are transformed beyond which the practical efforts of conventional restoration are feasible. They are also self-sustaining in the sense that they take time to form, and do not typically receive regular management. In this respect, they arise differently than designed ecosystems, which are assembled with specific goals in mind and are often heavily managed. Designed (or engineered) ecosystems comprise a variety of ecological approaches including reclamation (return a degraded ecosystem to productive capacity), green infrastructure, and agroecological systems. There are three elements that distinguish novel and designed ecosystems. Designed ecosystems typically require intensive intervention to create them, and ongoing management to sustain them; novel ecosystems do not. Second, the human intentions behind designed and novel ecosystems are usually different. Designed ecosystems exist in the service of human interests, including specific services (e.g. filtration, cooling, nature appreciation), aesthetics, and shifting value commitments toward green infrastructure; novel ecosystems arise typically through inadvertent human activity. Third, designed and novel ecosystems have different developmental pathways. Historical ecosystems are the starting point for restored, hybrid, and novel ecosystems; designed ecosystems are intentionally created. Designed ecosystems stand apart as providing a new origin for ecosystems of the future, including those that become novel ecosystems.

Key words: designed ecosystems, engineered ecosystems, green infrastructure, hybrid ecosystems, novel ecosystems, reclamation

Implications for Practice

- Novel ecosystems can be distinguished from designed ecosystems in several ways: in their origin, intention, and developmental pathways. This distinction has implications for how restoration may be practiced in the future.
- Novel ecosystems are self-assembled, along with historical and hybrid ecosystems. Designed ecosystems form a broad class of traditional and emerging ecological approaches. Restoration straddles the self-assembled and designed ecosystem divide.
- As natural ecosystems shift, and interest increases in designing ecosystems to reflect specific functions, restoration must necessarily adapt to ensure it reflects classical restoration (restore to an historical trajectory), expanded forms of restoration (different views of historical referents; more flexible goals), and new contributions in restoring functional attributes of novel ecosystems and the design specifications for designed ecosystems.

Introduction

Just a decade ago, the concept of novel ecosystems was barely visible. It was mentioned in a few early articles (Chapin & Starfield 1997; Milton 2003), but the term had not received any formal definition or found its way into management practices. With a recent spate of articles and a book-length synthesis, much has changed. The term has become widespread, being used in hundreds of scientific articles. The 101st annual meeting of the Ecological Society of America in 2016 carries the theme, "Novel ecosystems in the Anthropocene." The concept of novel ecosystems has hit a nerve. In doing so, the term and concept are bound to evolve rapidly in the "wild," and to move beyond the intentions of its early adopters. This is understandable and appropriate. The question is how far can the concept range before it undermines its explanatory value and usefulness? For example, is a designed ecosystem (e.g. a green roof) a novel one? Or, will it be eventually? Issues around how much human agency is appropriate in novel ecosystems are at the heart of an emerging and useful distinction between *novel* and *designed* ecosystems. I explore this distinction, and suggest that it helps point to an expanded role for restoration ecology in an era of rapid environmental and ecological change.

Why Novel Ecosystems?

Novel ecosystems are identified by three characteristics (Hobbs et al. 2013; Morse et al. 2014; Truitt et al. 2015). First, they

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comprise native and exotic organisms, often operating under biophysical conditions and selection pressures distinctly different from those that existed prior to significant human disturbance. Second, novel ecosystems are persistent, having developed metastable population, community, and landscape conditions that are both new and ongoing without extensive human intervention. Third, in practical terms, novel ecosystems cannot be restored to historical conditions (e.g. Gomes 2013; Graham et al. 2014; Acreman et al. 2014; Cloern et al. 2016). The definition is yoked with classical restoration theory, stipulating that a novel ecosystem exists at significant distance from historical ecosystems that are typically the focus of restoration ecology. In between historical and novel ecosystems are *hybrid* ecosystems that comprise historical and novel elements. Both novel and hybrid ecosystems arise as a consequence of human degradation, either as a single act (e.g. surface mining) or sustained activities (e.g. long-term cultivation followed by abandonment). A novel ecosystem is in effect a hybrid ecosystem that can no longer in any practical sense be restored to a pre-disturbance ecosystem. There is debate about whether such thresholds are real or apparent (Suding & Hobbs 2009; Bestelmeyer et al. 2011; Murcia et al. 2014), and concerns are raised about whether "practical" stands in for a lack of commitment to resolve intransigent or just very difficult restoration challenges (Hobbs et al. 2014*a*, 2014*b*).

Novel ecosystems also generated criticism. Simberloff suggests that along with recent reconsideration of best approaches to managing invasive species there is an "underlying argument [for] abandoning traditional restoration ecology in favor of 'novel ecosystems'" (Simberloff 2015). The novel ecosystems concept has been criticized for being unnecessary and overlooking the capacity for restoration science and practice to adapt to changing conditions (Murcia et al. 2014). There are misunderstandings, for example that the novel ecosystems concept replaces restoration; it does not, and instead provides a wider palette of options. Overlooked by some critics is the value in having alternate approaches for ecosystems that are not amenable to conventional restoration (Hobbs et al. 2014*b*). Concerns about novel ecosystems paving the way for unfettered intervention in ecosystems were anticipated in the development of the concept (Standish et al. 2013). There is also confusion over whether novel ecosystems are in any sense new, given that all ecosystems taken across a sufficient interval are novel (Jackson 2013). Although this much is true, the effect of the novel ecosystems idea is to point at recent activities tied with industrial activity or the Anthropocene (Mascaro et al. 2013). Several critical refinements (Morse et al. 2014; Truitt et al. 2015) to the definition posed by Hobbs et al. (2013) have been advanced, but the basic elements of the definition remain intact. Miller and Bestelmeyer (2016) suggest revisions to the concept (e.g. replacing a threshold between hybrid and novel ecosystems with a gradient of alteration), and a decision tree that brings novel ecosystems more usefully into the "big tent" of restoration. Criticism and concerns are essential in the development of any new framework, and especially one that offers new approaches to orthodox and traditional approaches.

Few of us are naive enough to believe that the concept of a novel ecosystem is purely descriptive. No formulation can be divorced from the social and intellectual setting in which the concept is embedded. The concept was developed for its descriptive role and as an attempt to address the limits of classical restoration in a rapidly changing world (Higgs et al. 2014). Novel ecosystems have caught on because the concept makes intuitive sense to many, but also because it fits a particular character of our times: one that is comfortable with admitting and responding to the extensive human role in transforming the planet (Standish et al. 2013).

To define an ecosystem as novel is to assign it distinctive characteristics that render it largely resistant to classical restoration. Restoration does not become irrelevant, but in the case of intervening in novel ecosystems traditional pre-disturbance goals may no longer be appropriate. Restoration of historical functional attributes is certainly possible with novel ecosystems, as is the management of historical elements within a novel ecosystem. Hulvey et al. (2013) explored a variety of management approaches for novel ecosystems; there is no single or axiomatic outcome. That an ecosystem is novel does not necessarily imply a particular intervention strategy, and indeed points to a larger suite of options that make restoration choices more complicated. This point has been obscured in the buzz to define how novel ecosystems are positioned in a rapidly changing world, or at least a world in which ecologists are concerned by the impacts of rapid environmental change.

Distinguishing Novel and Designed Ecosystems

Beyond restoration, a variety of other ecosystem approaches have developed concurrent with the recent rise of the novel ecosystem concept. By *ecosystem approach*, I refer to concepts and associated practices that describe distinctive ways of intervening in ecosystems. Driven by growing awareness of planetary boundaries (Steffen et al. 2015) and the need for constructive solutions for ameliorating human development impacts, emerging approaches involve designing ecosystems intended to solve particular problems (e.g. reducing urban heat island effects, reducing agricultural inputs, managing stormwater flows) (Ross et al. 2015). The rapid growth of these approaches alongside more traditional ecological practices such as restoration and reclamation can be viewed as the countervailing response to environmental, ecological, and social change. Green infrastructure encompasses ecosystems engineered to deliver specific services, including green roofs that provide thermal shielding along with aesthetic and biodiversity benefits (Hostetler et al. 2011). Agroecology and permaculture use ecological insights to achieve sustained production (Magdoff 2007; Ferguson & Lovell 2014). Food forestry, for example, mimics forest structure to create perennial polycultures providing a regular supply of desirable foods and medicines (Clark & Nicholas 2013). The long-standing practices of reclamation and rehabilitation have aimed for many decades to convert ecosystems damaged by industrial or agricultural activity to productive systems (Prach & Hobbs 2008). An example is the creation of wetlands following surface mining or oil sand mining (Roy et al. 2016).

What these approaches have in common is the use of ecological principles to inform explicit designs that produce functional systems primarily for human benefit. This stands in contrast (Table 1) to ecosystems that are self-assembling and either intact (historical) or in various stages of degradation or transformation (restored, hybrid, and novel). More often than not, such *designed* ecosystems follow an engineered or (landscape) architectural design process and require ongoing maintenance to achieve clear goals (although designed ecosystems can be designed for self-sustainability). This class extends beyond the three approaches described above, and is evolving rapidly. Emerging approaches in landscape sustainability (Musacchio 2013), biomimicry (Gamage & Hyde 2012), regenerative design (Cole et al. 2013), and even genomics and synthetic biology (Jeschke et al. 2013; Redford et al. 2013) point to a future in which many ecosystems (and organisms) are designed.

There may be temptation to apply the term, if not the concept, of novel ecosystems to a wide class of approaches that do not fit the emerging definition of novel ecosystems (e.g. Demuzere et al. 2014). In diluting the meaning of novel ecosystems there is the potential to produce confusion over appropriate goals, which risks treating novel ecosystems as those that can be manipulated for distinctly human goals. A significant concern about novel ecosystems is shifting from acknowledging the novel character of some ecosystems and sorting out the best way if at all to intervene to promote biodiversity or related ecological goals, to actively setting in motion novel ecosystems. Novel ecosystems are by definition functioning self-assembling ecosystems. Green infrastructure, agroecology, reclamation, and other emerging approaches intentionally create ecosystems largely from scratch, and sometimes have the goal of producing self-regulating ecosystems. Both types of approach—novel and designed ecosystems—are useful and perhaps important in a changing world, but there are risks in conflating them.

Those who find restoration an austere and demanding practice are attracted to the idea that novel ecosystems allow a wider array of options for many different kinds of challenges, including recovery of focal species (e.g. Stock et al. 2013). With novel ecosystems the focus is similar to ecological integrity and biodiversity goals for ecological restoration. In other words, the ecosystem comes first. Designed ecosystems may also embed commitments to ecological integrity and biodiversity, but explicit design guidelines favor specific functional or service benefits primarily for human interests. Designed ecosystems, a much broader class of approaches than represented by the relatively narrow definition of novel ecosystems, allow special purpose fully designed ecosystems (e.g. an urban rain garden for detaining surface water flow) as potential substitutes. There is little question conservation and restoration ecologists operate in a more complex operating environment than just two decades ago, and some guidance is beginning to appear that helps navigate an increasingly complicated environment (Higgs & Hobbs 2010; Hulvey et al. 2013; Kueffer & Kaiser-Bunbury 2013). With a commitment to ecosystem services, ecological infrastructure, ecological design, biomimicry, engineered ecosystems, synthetic ecologies (Mee & Wang 2012), and many parallel ideas and approaches that aim to use ecological processes and structures in the service of distinctly human benefits, there is bound to be growing concern and confusion over the proper role of restoration ecology.

The distinction between novel and designed ecosystems is based on three critical differences:

1 Intensive and repeated intervention is required to create designed ecosystems and to sustain them. In contrast, novel ecosystems arise through initial, sometimes inadvertent, human disturbance, but develop over time to form new, metastable conditions in response to new mixes of species and environment conditions. Although experience with explicit management of novel ecosystems is limited, there is little cause for ongoing management except to maintain ecological elements that contribute to biodiversity values or specific functions. It is also possible for designed ecosystems to become novel over time, especially designed ecosystems that are intended to be self-regulating, experience light management, or are abandoned.
2 The human intentions behind designed and novel ecosystems are usually different (Fig. 1). Designed ecosystems exist in the service of human interests, including specific services (e.g. filtration, cooling, nature appreciation), benefits to nature that are valued by people (e.g. biodiversity), aesthetics, and shifting value commitments toward new approaches such as green infrastructure. Some designed ecosystems also provide important local biodiversity improvements. Novel ecosystems are acknowledged for their distinctive ecological qualities first and foremost. They arise from human actions, but achieve their primary value as relatively unmanaged or wild ecosystems. As novel ecosystems run against the grain of recent conservation and restoration, functional arguments are often made to accentuate their social as well as ecological value.
3 Designed and novel ecosystems typically have different developmental pathways. Degradation of historically continuous ecosystems is the starting point for restored, hybrid, and novel ecosystems, which together form the class of self-assembled ecosystems (Fig. 2). The extent and duration of degradation influences the response. For example, a forested ecosystem harvested recently for commercial purposes may be amenable to restoration. A forested ecosystem converted to and long used for agriculture, and subsequently abandoned, may be resistant (hybrid) or practicably impossible to restore (novel) (Lindenmayer et al. 2015). Designed ecosystems embed positive value at the beginning of a project, and may evolve individually and in combination with other designed, historical, hybrid, and novel ecosystems to become significant components of the "whole landscape" (Hobbs et al. 2014*a*). Reclamation, green infrastructure, agroecology, and other emerging ecological approaches stand apart as providing a new origin for ecosystems of the future. Restored ecosystems sit about the boundary of self-assembly and design: a restored ecosystem can be a direct response to degradation (in this sense a self-assembled ecosystem), and at the same it can

Table 1. A variety of ecosystems are divided initially into two groups: self-assembled and designed. Novel ecosystems are categorized as self-assembled. Features pertaining to restoration/intervention and management characterize these ecosystems. In each case, the characterization is open to debate and counterexamples can be easily presented. For example, restored ecosystems are usually managed for ecological integrity but there are also many examples where sustained cultural practices (harvesting, burning) are prominent or project manifest distinctly cultural values (e.g. aesthetic features in the case of many urban restoration projects). Historicity refers to the significance of historical ecosystem composition and processes.

Type of Ecosystem		*Restoration/ Intervention Goal*	*Degree of Intervention*	*Ongoing Management*	*Historicity*	*Management Intention*
Self-assembled	Historical	Composition	None-negligible	None-low	Strong	Ecosystem-centered
	Restored	Composition first	Low	Low	Strong	Ecosystem-centered
	Hybrid	Composition and function	Low-moderate	Low-moderate	Moderate-strong	Ecosystem-centered
	Novel	Function first	Low	Low	Low-moderate	Ecosystem-centered
Designed	Reclaimed	Function	Moderate-heavy	Variable, low	Low	Human-centered
	Green infrastructure	Function	Heavy	Variable-heavy	Low, moderate	Human-centered
	Agroecological	Function	Variable, intensive	Variable, moderate	Variable, low	Human-centered

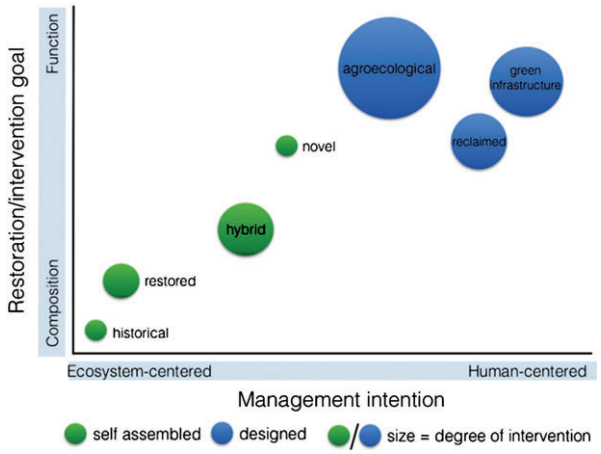

Figure 1. Ecosystem types arranged by restoration/intervention goals and management intention, and based on categorization provide in Table 1. This representation illustrates that self-assembled and designed ecosystems cluster distinctly. The size of each circle approximates the relative level of intervention.

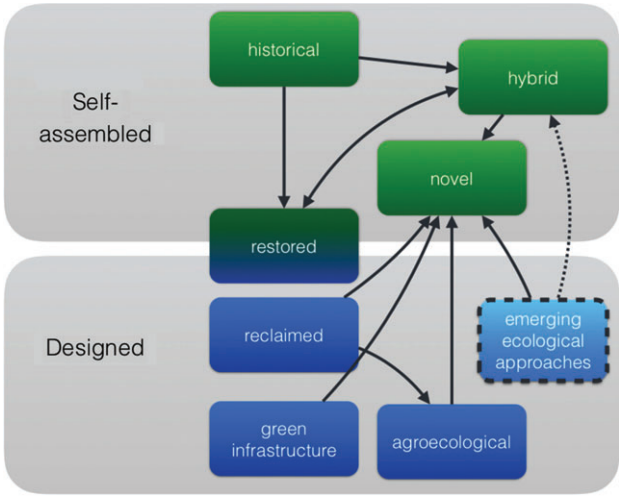

Figure 2. Novel ecosystems occupy a critical role as a trajectory for self-assembled and designed ecosystems. Restored ecosystems straddle the two categories being both self-assembled and designed. Restored ecosystems are typically intended to function with minimal management, but they arise (similar to reclamation) from a degraded condition. Restoration can also be considered from a design perspective (Higgs 2003). Designed ecosystems can over time either explicitly (as self-sustaining designs) or accidentally (e.g. abandonment) become novel ecosystems. It is less clear whether they can become hybrid ecosystems capable of restoration to historically representative ecosystems (indicated by dashed line).

be an explicit design for ecological integrity (a designed ecosystem).

For restoration ecologists designed ecosystems offer at least two restoration opportunities. A degraded designed ecosystem (e.g. a neglected green roof) may be restored to original design specifications. Depending on the original design specifications restoration may involve reference to local or regional historical ecosystem composition and processes. Under some conditions a designed ecosystem could be restored to some historically significant ecological condition, thereby transferring it to the historical-hybrid-novel continuum (e.g. a reclamation project that emphasized native species). Novel ecosystems are unresponsive to classical restoration with its explicitly and precise historical aim. However, there are ways in which restoration insights inform intervention in novel ecosystems (i.e. novel ecosystems arise conceptually and practically from historically continuous ecosystems) by recovering historical functions or focal native species. There are also ways in which degraded novel ecosystems, so defined, may be restorable (to conditions prior to degradation; not to a prior pre-disturbance native configuration).

Alas, distinctions are seldom perfect. Are there novel ecosystems that provide critical ecosystem services and reflect distinctly human intentions? Certainly, which is why many novel ecosystems have significant value and warrant careful intervention. Are there designed ecosystems that are also novel ecosystems? Yes, but only with the passage of time allowing the unmanaged interplay of native and exotic species and shifts in environmental conditions. For example, an abandoned food

forest comprising mostly agronomic species might eventually develop into a flourishing ecosystem comprising native and exotic species. It might be possible to intervene in novel ecosystems to restore biodiversity values, but not to restore it to a prior pre-disturbance condition (in the sense of classical restoration). In the end, the distinction is not sharp, and the region between novel and designed ecosystems will undergo continuous refinement as new approaches clarify and coalesce. It bodes well for restoration that it straddles a critical zone between novel and designed ecosystems.

The fact and concept of novel ecosystems have produced new ways of thinking about the role of ecological restoration (Hobbs et al. 2014*a*, 2014*b*), and many other emerging ecological approaches usher in an exciting if perplexing era for restoration and ecological management. Novel ecosystems are not without controversy, and there is hubris in believing that we can disrupt ecosystems and wait for the results in the form of ecological novelty. Ecological restoration is stimulated by concepts such as novel and designed ecosystems, and getting clear on the objects of proper focus is critical to long-term effectiveness (Suding et al. 2015). In delineating designed ecosystems, not only is it more clear what novel ecosystems are, it highlights novel ecosystems as being rooted in the processes of human transformation that motivate the restoration of damaged, degraded and destroyed ecosystems. The manifold variety of designed ecosystems, done carefully and with clear intention, will add considerably to effective biodiversity especially in urban and urbanizing regions. Restoration will come to play a role in these ecosystems, too.

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