Opinion

A critique of the 'novel ecosystem' concept

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The 'novel ecosystem' concept has captured the attention of scientists, managers, and science journalists, and more recently of policymakers, before it has been subjected to the scrutiny and empirical validation inherent to science. Lack of rigorous scrutiny can lead to undesirable outcomes in ecosystem management, environmental law, and policy. Contrary to the contentions of its proponents, no explicit, irreversible ecological thresholds allow distinctions between 'novel ecosystems' and 'hybrid' or 'historic' ones. Further, there is no clear message as to what practitioners should do with a 'novel ecosystem'. In addition, ecosystems of many types are being conserved, or restored to trajectories within historical ranges of variation, despite severe degradation that could have led to their being pronounced 'novel'.

Challenging current conservation and restoration practices

New concepts that challenge existing paradigms drive science and innovation. However, presumably revolutionary concepts must be based on solid arguments and evidence, in particular when they affect how we manage the ecosystems on which all life depends. Doak *et al.* [1] analyzed the implications of uncritically adopting a new human-centered conservation approach based on opinions, untested assumptions, and unwarranted conclusions. Here we discuss a similar case in which a new ecological world order [2] is proposed without the necessary substance and supporting evidence, but with potentially disturbing policy implications. The concept of 'novel ecosystems' [2–4] advocates embracing novelty as a way to move forward and away from 'traditional' conservation and restoration approaches. Our goal is to analyze the concept, its foundations, and its policy implications objectively.

A 'novel ecosystem' refers to a new species combination that arises spontaneously and irreversibly in response to anthropogenic land-use changes, species introductions, and climate change, without correspondence to any historic ecosystem. The 'novel ecosystem' concept, first introduced by Chapin and Starfield [5], was brought to the attention of the restoration and conservation communities in 2006 [3]. Presented as a new paradigm [2] aligned with the proposed synthetic fields of 'Intervention Ecology' [6] and 'New Conservation Science' [7], the concept of 'novel ecosystems' and its definition have mutated continuously (Table S1 in the supplementary material online) sometimes to address criticism [2,3,8–11] and sometimes with unresolved conflicts [12,13]. In its latest definition, a 'novel ecosystem' is 'a physical system of abiotic and biotic components (and their interactions) that, by virtue of human influence, differs from those that prevailed historically, having a tendency to self-organize and retain its novelty without future human involvement' [12]. This definition is

Glossary

Ecological rehabilitation: in the broad sense, the improvement of ecosystem functions without necessarily achieving a return to 'predisturbance' conditions. Emphasis is generally on restoring ecosystem processes and functions to increase the flow of services and benefits to people [51,52].

Ecological restoration (ER): 'The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed' [52]. The term is often used broadly to mean returning a site or system to 'pre-disturbance conditions'. It implies connecting an ecosystem, as it occurred and developed in the historical past, to its future potential to evolve and adapt. The notion of 'historical continuity' is relevant and useful [51].

Ecological threshold: a 'tipping point' at which an ecosystem, under pressure from environmental drivers of change, shifts to an alternative stable state (sometimes referred to as state-change).

Ecosystem resilience: the capacity of an ecosystem to tolerate disturbance and recover autonomously by natural regeneration without collapsing or shifting into a qualitatively different state controlled by a different set of processes [53].

Evolutionary rescue: the possibility that rapid evolutionary processes may allow a population to adapt even to abrupt environmental changes.

Reference ecosystem (or reference model): one or more natural or semi-natural ecosystems, ecological descriptions, or carefully selected attributes of corresponding ecosystems that are assembled to serve as models, benchmarks, and rallying points for planning, executing, and monitoring ecological restoration projects.

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still impaired by logical contradictions and ecological imprecisions. We propose that the overall foundations and implications of this concept are as troublesome as the semantic details.

'Novel ecosystems' constitute a special case of ecosystem transformation resulting from species invasions and environmental change [2]. Some proponents of the concept assert that because of the global nature of climate change, all ecosystems are at risk of transformation by extinctions and invasions. Moreover, the pervasiveness of the human footprint suggests to some that no corner of the earth can escape transformation [14]. Consequently, all systems previously considered 'wild' or 'natural', and the abandoned remnants of previously managed systems (particularly agricultural lands), are likely to become so profoundly transformed that no effort will suffice to return them to their historic state [2]. In this scenario, conserving and restoring ecosystems is a futile endeavor [15], driven by sentimentality (R.J. Hobbs, cited in [16]) and psychological impairment [8]. Instead, efforts should focus on steering ecosystems towards a desirable state or away from an undesirable state [6], none of which involves an historical pre-disturbance condition (hence its difference from restoration). This line of thought, however, contains ambiguous statements and can lead to misconceptions and poor policy, especially when ecological thresholds are confused with socioeconomic and political ones, as discussed below.

Faulty assumptions and oversights of the 'novel ecosystem' concept

'Novel ecosystems' are ubiquitous [2] and constitute a 'new normal' [17]

The above-cited oversimplification is based partly on inferences drawn at an inappropriate scale. The argument that most of the world's ecosystems are moving into 'novel' condition [2,17] is based on the global human footprint map [18], which shows potential human disturbance at a coarse scale based on proxy variables such as roads or human settlements. However, a closer look at the ecosystem scale shows that many ecosystems are well preserved, well managed, or only mildly degraded [19,20] with sound prospects for restoration.

An analysis of forest cover trends over a 10 year period in 16 050 municipalities in Latin America and the Caribbean indicated that, although some areas are affected by deforestation, in many others the extent of natural forest is stable or increasing [19]. Specifically for Colombia, a country-wide net gain of forest cover of almost 17 000 Km^2 has occurred between 2000 and 2010 [21]. Furthermore, in the mega-diverse 'Eje Cafetero' region of the central-western Andes of Colombia, 208 000 hectares of cloud forest are being conserved and restored in what appears as a thoroughly transformed region in human footprint models. Geographical analysis at a finer scale shows that much native forest is intact and supports a complete biota, including large mammals such as mountain tapir (*Tapirus pinchaque*). Ecological restoration of degraded pastures based on an historical reference (see Glossary) has aided recovery of the cloud forest biota and ecosystem functioning [22,23].

Similar trends are observed on other continents. For example, in western Africa the Transfrontier Reserve of Benin, Burkina Faso, and Niger (http://www.parks.it/world/NE/parc.w/Epar.html), assisted natural regeneration is facilitating dramatic comeback of savanna vegetation in large areas without major cost and with few invasive organisms (J.A., unpublished data, February 2014). These examples, and many others, show that blanket statements about the relentless global spread of 'novel ecosystems' or the irreversibility of ecosystem change are unsubstantiated. Similarly, assisted regeneration coupled with sound management practices in many forest systems is currently observed in eastern North America and southern Europe [24].

'Novel ecosystems' result from predictable and unavoidable responses in species distributions caused by climate change or other global changes

The 'novel ecosystem' concept is based on the premise that we should be 'pragmatic' and accept unavoidable, widespread, and irreversible changes in ecosystems caused by climate change, biological invasions, and other altered global processes (e.g., nitrogen deposition) [6]. This premise presents an inaccurate forecast for the planet. Although evidence accumulates that many species are responding to global change by migrating and invading other ecosystems, our ability to predict climate change is still limited, especially at local and regional scales that are relevant to conservation and restoration projects. Hence, abandoning attempts to restore damaged ecosystems over an uncertain future might not be wise. A study modeling potential biome responses to climate change in the tropical Andes found that, depending on greenhouse gas emission scenarios and time horizons, 75–83% of the biomes in the region will not change [25]. Importantly, many species have pre-adaptations to climate change, as shown by their recent evolutionary history [26].

The growing literature on evolutionary rescue suggests that we should not automatically assume that species or assemblages cannot adapt to rapid changes [27]. Although populations shift their distributions in response to climate change, entire ecosystems and natural species assemblages may be remarkably resilient. For example, although birds in Peru are shifting their distribution upwards as a result of climate change [28], the shift is much smaller than expected. In addition, there is great uncertainty about which species combinations, based on species functional traits, will match new biophysical conditions, exhibit resilience, maintain biodiversity, and provide ecosystem services to people [29].

These facts argue for a precautionary principle of conservation and restoration. Rather than embracing invasion-driven 'novel ecosystems' as a 'new normal' [17], we should seek to reestablish – or emulate, insofar as possible – the historical trajectory of ecosystems, before they were deflected by human activity, and to allow the restored system to continue responding to various environmental changes [30,31].

'Novel ecosystems' tend to self-organize and retain their novelty

This premise (see [4,12]) is based on untested assumptions that current ecosystems are not resilient, whereas 'novel

Box 1. Two examples of restoration success

Reconciling industry with restoration in a biodiversity hotspot

Currently, Alcoa of Australia produces 11% of world alumina by mining land under 600 ha of biodiverse jarrah (*Eucalyptus marginata*) forest annually in SW Australia. Initially, post-mining rehabilitation consisted of stabilizing the land with non-native pines and other trees [54]. Subsequently, the company embarked on an ambitious program to restore the native woodland ecosystem. Decades of research and development have achieved almost total reinstatement of native plant communities comparable to intact 'reference' jarrah forest sites. Birds, generalist foraging mammals, and some ant species also exhibit species compositions and densities comparable to those of unmined forest [54]. These results suggest these forests are likely to recover their original plant species composition and most of their terrestrial vertebrates and ants. National restoration standards for post-mining sites cite the work of Alcoa as a model (http://www.minerals.org.au/file_upload/files/resources/enduring_value/mine_rehab.pdf).

Using maintenance management of invasives in a dune restoration

Beginning in 1992, non-native plants in a pilot 11 ha area of Lanphere Dunes in the Humboldt Bay National Wildlife Refuge in California, overgrown with European beachgrass (*Ammophila arenaria*) and threatened by spreading ice-plant hybrids (*Carpobrotus edulis* × *C. chilensis*), were manually removed [55]. This was done piecemeal to avoid dune collapse, in an effort to restore the system to the historical status thought to have existed before substantial EuroAmerican modification. The aim was to restore abiotic processes that maintain a dynamic dune ecosystem. Because of community concern about herbicides, and to avoid impact on vegetation by heavy equipment, the project was initially conducted by repeated digging and pulling. Culms of the native dune grass *Elymus mollis* subsp. *mollis* were planted in cleared areas. Beachgrass and ice-plant were eliminated after 5 years. Both these species continue to invade from surrounding areas but are maintained at low densities with annual spot treatments primarily of manual removal. Transplanted *Elymus* survival was high, and native species have continued to spread. The project gradually transformed overstabilized dunes to a more natural, dynamic morphology and a community wholly dominated by natives. To date, 12 km of coastline near Lanphere have been cleared of beachgrass and other invaders.

ecosystems' will be. Unless mechanisms to secure their resilience are determined and implemented, it seems logical that 'novel ecosystems' will continue to change in response to the drivers that produced them in the first place, including unpredictable incursions of new alien species. Novelty is implicitly transient, but it is unclear for how long the transformed ecosystem will remain novel or if it will attain a stable state [31].

Given chronic impacts of human societies on ecosystems, virtually all ecosystems in contact with humans have been under constant renewal, and are therefore 'novel', for millennia, as has been previously noted [14,32]. In fact, Hobbs *et al.* [2] acknowledge that '. . . all ecosystems can be considered novel when placed in the appropriate temporal context'. The question, then, is how much change must human influence exert for a site or system to qualify as novel, and for how long is the status of novelty acknowledged? This issue is not yet addressed in the 'novel ecosystem' literature.

'Novel ecosystems' have crossed irreversible thresholds

At the core of the 'novel ecosystem' concept is the idea that an ecological threshold (see Glossary) has been irrevocably crossed – from an historical to a 'hybrid' condition that eventually ends in novelty [2,33]. However, crossing a threshold need not imply irreversibility [34]. The implication that ecosystems that have crossed a threshold cannot be restored is unsubstantiated by current evidence [35]. Indeed, restoration efforts have demonstrated that many thresholds can be crossed back with appropriate efforts.

Hobbs *et al.* [2] state that the distinction between novel and historic '. . .is somewhat arbitrary, and the exact point at which an ecosystem is considered novel cannot necessarily be universally applied'. Indeed, predicting and quantifying the occurrence of thresholds or threshold crossings is rarely done empirically and requires long-term datasets that account for an historic range of variability across spatial and temporal scales [36,37]. Until metrics exist that allow ready quantification of ecological thresholds and the likelihood of irreversibility, the concept remains impractical.

The concept of 'novel ecosystem' and its associated novel approaches to ecosystem management are necessary because the discipline of ecological restoration is creating false expectations and wasting limited resources [2,6]

All ecosystems should be considered candidates for restoration, regardless of the requisite resources. This does not mean that all damaged ecosystems can or should be restored, given limited resources (e.g., [38]). Instead, they should be evaluated for feasibility, desirability, and cost-effectiveness, on a case-by-case basis, so that informed and science-based policy decisions can be made, in consultation with scientists, restoration practitioners, stakeholders, and advisors.

Restoration is a new discipline in which techniques and fundamental principles are still under development, and in which failures are an important part of a learning process to improve methods and results [39]. Despite setbacks, which are expected in a new discipline, increasing evidence indicates that restoration very often not only is feasible but also can yield multiple social and economic benefits (specific examples are given in Box 1).

Recent syntheses show promising trends, whereby human-damaged ecosystems can be at least partially restored to pre-disturbance or reference 'undisturbed' states. A meta-analysis of 89 terrestrial and aquatic ecosystem restoration projects showed that restored sites recovered on average 80–86% of biodiversity and ecosystem services, relative to their paired reference ecosystems, and showed improvements of 125–144% over degraded ones [40]. Similarly, a meta-analysis of 621 restored and created wetlands around the world showed that sites recovered on average 75% of the values of reference 'undisturbed' conditions within 50–100 years [41]. These values were closer to reference levels in projects restored after 1995 than in those restored before 1995, which suggests ongoing improvements in restoration technology. These results show that restoration expectations can be realistic and that investments yield ecologically significant results.

Implications for policy

Concepts that are ambiguous and do not develop a solid theoretical basis often pass without consequence.

Box 2. Outstanding questions

To test the 'novel ecosystem' concept empirically it is crucial to answer the following questions:

- How common are non-linear dynamics (and associated thresholds) in the transformation trajectory of ecosystems, and how frequently are they irreversible?
- What factors determine ecosystem resilience to climate change and species invasions?
- Is a new paradigm needed to manage highly disturbed ecosystems better for greater ecosystem service delivery?

However, in this case, the 'novel ecosystem' concept has captured the attention of scientists [see the Strategic Environmental Research and Development Program (SERDP) project on transforming US Department of Defense lands in Hawaii into carbon storage systems – http://www.serdp.org/Program-Areas/Resource-Conservation-and-Climate-Change/Climate-Change/Land-Use-and-Carbon-Management/RC-2117/RC-2117/%28modified%29/13May2011] [42,43], as well as journalists [16,17,44], and more recently the public (http://www.en.wikipedia.org/wiki/Novel_ecosystem) and policymakers, before it has been subjected to the scrutiny and empirical validation inherent to science (Box 2). The lack of rigorous scrutiny can lead to undesirable outcomes in law and policy.

After 30 years of dedicated work, the science and practice of ecological restoration are now called upon by the European Commission [45] and by the UN Convention on Biological Diversity (CBD) [46], as well as by many national governments and major non-governmental organizations [e.g., International Union for Conservation of Nature (IUCN), The Nature Conservancy (TNC), World Resources Institute (WRI), and World Wide Fund for Nature (WWF)] to help society scale-up restoration actions and achieve new levels of effectiveness in fighting biodiversity loss and ecosystem degradation, and indeed to attenuate anthropogenic climate change. Unintended outcomes of the 'novel ecosystem' concept present serious risks. These include:

Opening the door to impunity

The 'novel ecosystem' label may provide a 'license to trash' or 'get out of jail' card for companies seeking to fast-track environmental permits or to avoid front-end investment in research, offsets, and restoration. At the very minimum, it knowingly lowers the bar [10]. Adopting 'novel ecosystem' thinking may also legitimize the tendency of society to ignore long-term environmental and ecological negative impacts of business-as-usual with respect to development, pollution, and natural resources depletion and mismanagement.

Sending conflicted messages to governments worldwide

Accumulating evidence on the knowhow available and true potential to restore degraded ecosystems at large scales has reached international and national government programs. The UN Environmental Program, for example, included restoration in two Aichi Biodiversity Targets (14 and 15). At Rio+20, held in June 2012, the UN Convention to Combat Desertification (UNCCD) proposed to 'strive to achieve a land degradation neutral world' by 2030 [47]. To achieve this ambitious goal, the UNCCD affirms that increased investments in dryland restoration and rehabilitation are essential (http://www.un.org/apps/news/story.asp?NewsID=48067#.U6Bc9PldUeg). This, in turn, would help to meet many Aichi Biodiversity Targets, as well as those of all three Rio Conventions – the CBD, the UNCCD, and the United Nations Framework Convention on Climate Change (UNFCCC) [48].

Spurred by the CBD, among other drivers, policymakers increasingly call for large-scale projects and programs. Existing programs are in Australia (Gondwana Link and the Great Eastern Ranges projects), India (River Linking Project), the Danube River (shared by 11 countries), the Mesoamerican Biological Corridor, North America (the Yosemite to Yukon project and the Adirondacks to Arcadia project), and Brazil (Pacto Mata Atlântica). Rhetoric about 'novel ecosystems' could lead countries and international organizations to lower standards or alter objectives for these ambitious pioneering efforts. It could also lead to imprudent relaxation of early detection and effective controls of biological invasions.

Hobbs *et al.* [4,12] state that the 'novel ecosystem' idea is not against traditional conservation approaches; not a suggestion that traditional restoration is no longer relevant; not an argument for 'giving up'; and not an argument that novelty is good *per se*. One can only hope that other scientists, as well as managers and policymakers, will keep these caveats in mind when pondering statements to the contrary in previous and widely disseminated papers [2,6,8] and the popular literature [44].

Concluding remarks and future directions

Is the 'novel ecosystem' concept a step forward or a paradigm shift in ecosystem management, restoration, and protection as its proponents contend? They argue that a new paradigm is needed to help dislodge the view that nature is static, supposedly held by traditional conservationists and restoration practitioners, and that we should stop trying to return to a pristine, natural state. However, the age-old balance-of-nature myth has long been replaced by a nature-in-flux model [49], and conservation and restoration biologists have for many years recognized the need to incorporate the reality of change in conservation planning and action and to account for the presence and agency of people.

Principle 5 of the CBD [46] states that conservation of ecosystem structure and function, to maintain ecosystem services, should be a priority target. Principle 9 states that management must recognize that change is inevitable. These principles allow innovative interventions to maintain function, including using species with adequate functional properties. The ecosystem approach [47] goes one step further in making explicit that the landscape context must be considered in planning ecosystem management and environmental interventions of any kind and also in recognizing the limits to what can be achieved.

To develop a pragmatic and operational framework for deciding when and how to intervene (as some proponents claim [33]), 'novel ecosystem' proponents must first demonstrate how one recognizes a hybrid state, when and why an irreversible threshold has resulted in an ecosystem shifting to a new stable state, and that restoration is impossible. Attempting to suggest new management approaches without first resolving these fundamental issues merely generates confusion among land managers and policy makers.

In summary, there is no need to describe a new set of goals because of accelerating global and climate change. Socioeconomic and cultural thresholds to restoration exist more clearly than scientific or ecological ones [50]. The two types of thresholds must not be confused. At a time of growing demand for investments in ecological restoration, and for scaling up to landscape and bioregional level restoration, the 'novel ecosystem' concept merits discussion but is fraught with potential risks.

We therefore propose an alternative view. First, avoid using the terms 'novel' and 'hybrid' ecosystems, because these are 'non-novel', ill-defined theoretical constructs (particularly in discussion of management tools) until the substantial issues raised here are resolved. Second, although we agree that rates of anthropogenic changes have increased, society must increase its scientific and policy efforts to avoid further loss of biodiversity and ecosystem function by conserving and restoring ecosystems in new and more effective ways. Scientists must strive to understand the processes of ecosystem degradation, invasion, and recovery, as well as strive to improve the effectiveness of conservation and restoration. Third, ecological restoration is an emerging field of action-oriented outcomes combining science, technology, and societal values, but has not yet achieved the scientific maturity to decide the point of 'no return' for an ecosystem. No proof of ecological thresholds that would prevent restoration has ever been demonstrated. Talk of such thresholds often masks a very different reality. Often, the threshold that obstructs a restoration project is not its ecological feasibility, but its cost, and the political will to commit to such a cost. Societies may decide not to restore a damaged ecosystem, but the debate and negotiations should not be based on the notion of non-feasibility, nor should inherent biodiversity values be abandoned in favor of 'functional' values. Deciding the fate of an ecosystem impacted by disturbance and invasive species requires compromise with social values balanced by both the economic costs of restoration and the socioeconomic costs of not restoring.

What is at stake is whether we decide to protect, maintain, and restore ecosystems wherever possible or else adopt a different overall strategy, driven by a vision of a 'domesticated' Earth, and use a hubristic, managerial mindset. Scientists should exercise caution when making recommendations that might undermine initiatives and diminish investments intended to protect or restore natural ecosystems.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tree.2014.07.006.

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