Aligning restoration science and the law to sustain ecological infrastructure for the future

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Ecological restoration as grounded in modern science is based on a systems perspective – it seeks to recover ecological systems characteristic of past or least-disturbed contemporary landscapes. This requires recovery of organisms along with the ecosystem features and dynamic processes that support them. Since self-sustainability is the goal, it also requires a landscape and environmental context that supports recovery of the system. As restoration becomes more widely practiced, so too are many specialized forms of environmental intervention, such as those associated with reducing the impacts of development, promoting recovery of endangered species, and achieving compensatory mitigation. These may be valuable and may also be informed by ecological science but they differ substantially from ecological restoration because they are not necessarily focused on recovery of a self-sustaining living system characteristic of past or least-disturbed landscapes. The US legal system has failed to make this distinction. Federal statutes do not explicitly define restoration and in fact do little to constrain or even guide this process; if this is not rectified, net ecological losses will continue to occur. Scientists and policy makers can add precision to the use and practice of ecological restoration and other, more specialized forms of restoration, to ensure a future that can support ecosystems and the people that depend on them.

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Launched in 1991, the Ecological Society of America's (ESA's) Sustainable Biosphere Initiative (Lubchenco *et al.* 1991) emphasized the role of basic ecological science in reducing environmental degradation. Fifteen years later, ESA embraced an expanded research agenda, focusing on the recovery of ecosystems by promoting the science of ecological restoration and design (Palmer *et al.* 2004). While the practice of restoration is well-established, testing and advancing the underlying ecological theory is relatively new (Young *et al.* 2005). Today, restoration is an important environmental policy tool, and commitments to restore ecosystems exist at regional, national, and international levels (Aronson and Alexander 2013). The US Departments of Agriculture, Commerce, Defense, and the Interior support a vast array of programs that promote restoration of coastal bays, forests, wetlands, lakes, streams, and even major river basins. Similar investments have been made in the European Union, particularly since the adoption of the Water Framework Directive in 2000, which set targets for achieving "good ecological status" for waterways (Haase *et al.* 2012) through the restoration of forests, bogs, and peatlands, and their associated biodiversity (Lammerant *et al.* 2013).

Today, the term "restoration" is being adopted more broadly to include a range of activities that diverge from ecological restoration, perhaps because Congress and state legislatures rarely define "restore" or "restoration" in statutory text, leaving it to administrative agencies to add details to the concept in their implementing regulations. While some agency regulations define restoration, the imprecise nature of these definitions permits an array of interpretations that justify a wide variety of activities, including outcome-focused actions that are substantially different from ecological restoration. Conversion of mine-pit lakes to reservoirs, creation of green spaces on abandoned brownfield sites, and engineering artificial wetlands along highways, for instance, may be branded as restoration (Crowe *et al.* 2007; McCullough and Van Etten 2011; Hartley *et al.* 2012). In reality, such actions

In a nutshell:

- The science of ecological restoration today emphasizes recovery of self-sustaining living systems, including both the organisms and the environmental factors that support them
- In the US, environmental statutory law assumes no definition is needed for the term "restoration", and lacks the clarity in terms necessary to differentiate between ecological restoration and more specialized environmental interventions
- This lack of statutory clarity creates confusion over implementation of regulations and policies by federal and state agencies, leading to differing practices across the US and greater uncertainty with regard to environmental outcomes, and thus more net loss of natural resources
- Because the ability of ecosystems to support humans in the future will increasingly rely on both creative environmental interventions and ecological restoration, efforts to clearly distinguish between the two in legal and management contexts are essential
- Processes for achieving such clarification are available

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are meant to achieve highly specialized objectives. Ecological principles may inform these activities but the distinction between creating ecological infrastructure and restoring whole ecosystems is important, and not merely a matter of semantics.

Many unintended consequences could be avoided if ecological restoration were clearly defined and distinguished from other forms of environmental intervention. Here, we explain why this is the case, using the US legal system and the variety of projects it characterizes as restoration as examples. We outline a path forward in which science and policy can add precision to restoration operations.

Scientific basis for ecological restoration

Deciding when, where, and why ecological restoration projects should be implemented is clearly determined by society, and is meant to benefit humans. But the process of determining how to design, physically implement, and evaluate projects is firmly grounded in ecological science, including fundamental principles of species and community ecology that date back to work by Clements, Gleason, and many others (see Falk *et al.* 2006). The purpose of ecological restoration is to re-establish a self-sustaining system that includes not only organisms but also those aspects of the environment that support them (eg flow or fire regimes, certain types of soils or landscape configurations; Panel 1). This bare-bones definition is consistent with both the origins of the practice and the definition agreed upon by a broad constituency of scientists and practitioners associated with the Society for Ecological Restoration (SER 2004), and is supported by a large body of ecological research (eg Van Andel and Aronson 2012; Temperton *et al.* 2013). At its core, restoration uses a systems perspective to identify actions likely to result in a living "unit" that is self-sustaining and consistent with its landscape setting and environmental context (Suding *et al.* 2015).

An ecologically restored landscape need not be identical to some historical or contemporary reference system (Balaguer *et al.* 2014) – instead, historical and contemporary conditions provide information that guides the placement and design of a restoration project (Higgs *et al.* 2014). A fundamental property of natural systems is that they vary over time and space but do so within limits. Information about the historical or contemporary range of variability in the abundance and composition of ecological communities, environmental processes, and characteristics of the landscape can help in identifying target goals for restoration and ultimately could be used as a means of assessing outcomes. These ranges shed light on what factors control the state of a system and therefore the environmental contexts within which it can persist, the rate at which it changes in response to variations in environmental conditions, and the ongoing direction of change (Wiens *et al.* 2012). Any major expected environmental changes (eg urbanization) must be factored into the design of the project to ensure that the system can persist. If it becomes apparent that future environmental conditions are going to be outside the range of historical and contemporary variability, then ecological restoration may not be possible and other alternatives should be considered, such as promoting climate resilience or endangered species recovery.

Legal basis for ecological restoration

In the US, Congress and state legislatures have enacted statutory programs delegating authority to administrative agencies to fund, authorize, carry out, or mandate restoration work. Statutes also charge agencies with issuing and enforcing regulations and policies to implement the statutory provisions, and agencies are given the authority to issue permits or provide funding to third parties to carry out restoration programs. The flexibility that an agency has in interpreting what is meant by restoration is dictated by the specificity of the statutory provisions and terms – agencies must follow the statute – as well as whether the statute or agency regulations and policies follow what lawyers refer to as a "rules, standards, or principles" approach. Rules are the

Panel 1. Characteristics of ecological restoration

Characteristic	Explanation
(1) Contains biological assemblages characteristic of a reference system of similar type	*Assemblage* refers to the identity, relative abundance, and functional attributes of taxa; *reference* refers to a least-disturbed system in which the assemblage is within the historical or contemporary range of variability
(2) Has the biophysical features and processes needed to sustain the characteristic biological assemblages and support ecological functions	*Features* are biophysical attributes such as habitat and system-level structure and pattern that are within the range of variability of the reference site (eg a floodplain is a structural attribute of rivers, and its connectivity to the water and land is an aspect of pattern); *processes* include dynamic features characteristic of the system that are of societal interest or are necessary for the maintenance of the assemblages (eg primary production, river discharge)
(3) Is self-sustaining	Systems that are *self-sustaining* are in landscape and environmental contexts that require little or no ongoing human intervention and maintenance over the long term

most specific and objective, and can therefore substantially limit an agency's discretion in defining restoration; for example, a rule for ecological restoration might specify the exact types of vegetation required to be used. By contrast, standards define a set of mandatory considerations to guide decisions but allow the agency a greater range of choices or decisions; for instance, a standard might require the agency to consider whether the types of vegetation being used are native to the ecosystems being restored, leaving it to the agency to decide specific types to use. Least constraining of all are principles, which establish broad goals the agency must strive to attain; for example, a restoration principle would require the agency to achieve "ecological integrity", which has little effect on specific choices like the type of vegetation to be planted.

In general, federal restoration statutes use standards and principles that are broadly stated and do not align with ecological restoration science. Statutes typically do not explicitly define restoration in terms of a self-sustaining system that includes organisms and the environmental processes and features that support them, and they do not specify that landscape setting and environmental context must be consistent with self-sustainability. A project may be implemented at the same position in a watershed where an ecosystem existed historically but the present-day landscape context may no longer be able to sustain that type of system, thus necessitating long-term maintenance. The need for a robust landscape-based approach to the selection of sites for wetland restoration projects has been emphasized because of the large number of underperforming projects; poor performance often stems from land-use changes in the watershed that render the hydrology inadequate for supporting a wetland (White and Fennessy 2005; Hunter *et al.* 2012). In some cases, consideration of landscape context is needed because the spatial arrangement of habitats is critical to the restoration goal. For example, the restoration of vernal pools to successfully support many amphibians requires the proximity of existing pools nearby – this is because some amphibian species are organized as metapopulations and can persist in a landscape only if individuals are able to disperse to different pools (Calhoun *et al.* 2014).

Federal restoration statutes are vague and do little to limit what can "count" as restoration or even guide restoration; there are a few exceptions, but even these offer only partial standards for ecological restoration (WebPanel 1). For example, the Water Resources Development Act of 2007 required the US Army Corps of Engineers (USACE) to develop guidelines for "protecting and restoring the functions of natural ecosystems" (WRDA 2007 §2031). However, the statute does not define "restoring", "functions", or "natural". When details are provided in federal statutes they are generally limited to undefined standards, such as requiring that restoration return the ecosystem to "natural", "native", or "historical" conditions, or else they incorporate broad principles such as "ecological integrity". The US national estuary restoration statutes usefully emphasize "self-sustaining" as a standard, but the term "system" could be interpreted in a variety of ways under the statute and there is no mention of biotic assemblages (33 US Code 2902). Prerequisites dealing with ranges of variability and environmental context are typically not included in federal restoration statutes. Scientists have pointed out that such open-ended descriptions have promoted an undue emphasis on physical habitat, even though that may not be the system component that is limiting ecological recovery (Palmer *et al.* 2014).

In terms of their regulations and policies, agencies have done little to resolve these open-ended statutes on restoration. The National Oceanic and Atmospheric Administration, for instance, defines "restoration" for the purposes of the Natural Resource Damages Assessment and Restoration Program to mean "any action (or alternative), or combination of actions (or alternatives), to restore, rehabilitate, replace, or acquire the equivalent of injured natural resources and services" (15 Code Fed Reg 990.30). When agencies have attempted to provide more precise definitions, they have done so in a way that again does not approach restoration from a systems perspective. For example, the US Fish and Wildlife Service (USFWS) defines "restoration" for the National Coastal Wetlands Conservation Grant Program as "the manipulation of physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded wetland" (50 Code Fed Reg 84.11). Functions are not defined, and the "or" in the language provides a great deal of interpretive latitude.

The most substantive description we found in any agencies' regulations is the one advanced by the Wetland Reserve Program of the Department of Agriculture's Natural Resources Conservation Service, which states that: "Wetland restoration means the rehabilitation of degraded or lost habitat in a manner such that: (1) The original vegetation community and hydrology are, to the extent practical, re-established; or (2) A community different from what likely existed prior to degradation of the site is established. The hydrology and native self-sustaining vegetation being established will substantially replace original habitat functions and values and does not involve more than 30 percent of the wetland restoration area" (7 Code Fed Reg 1467.3).

In summary, under federal restoration statutes, restoration is "whatever agencies say it is" in their regulations and policies, and these agencies have thus far not supplied much detail. Given the sparse language in most statutes regarding restoration, agencies have retained maximum flexibility, making it difficult to legally contest their choice of restoration rules, standards, and principles, or their selection of restoration methodology.

When restoration projects are not ecological restoration

Environmental law in the US has also extended restoration to include specialized purposes that go far beyond the bounds of a scientifically grounded definition of ecological

Figure 1. *Compensatory mitigation projects are undertaken to comply with US Clean Water Act requirements to offset permitted impacts to aquatic natural resources. Their goal, however, is not necessarily to recover a self-sustaining natural ecological system. Stream creation projects undertaken to offset mining impacts, such as those associated with mountaintop mining in Appalachia (a), do not result in resources comparable to natural systems (b). Ecological functions and structures have also been found lacking in the majority of wetland mitigation projects that have been studied. Water may be present but hydroperiod is not restored and plant assemblages may bear little resemblance to those of a natural wetland (c); in other cases, water is never present on the site (d).*

restoration (WebPanel 2). For example, in the 1990s, the USACE and the Environmental Protection Agency (EPA) developed a water resources compensatory mitigation policy under Section 404 of the Clean Water Act, as a way of facilitating development permitting while in theory maintaining a national goal of "no net loss" of aquatic resources; the informal policy documents describing the program did not mention ecological restoration. In 2008, the agencies adopted a formal administrative rule and mentioned restoration over 150 times in the Federal Register text explaining the rule (USACE/EPA 2008), and dozens of times in the rule text. However, the rule defines "restoration" only loosely as "the goal of returning natural/historic functions to a former or degraded aquatic resource" (40 Code Fed Reg 332.2) and a great deal of discretion is given to regional permitting authorities to interpret and implement restoration. Other examples of specialized purposes are related to species-specific habitat conservation under the Endangered Species Act and the use of an ecosystem services framework by various federal agencies such as the Forest Service (WebPanel 2).

While compensatory mitigation, species conservation, and the provision of ecosystem services are valuable to society and are important components of a complete natural-resources policy, their purpose is not to restore self-sustaining ecological systems with the full suite of organisms and ecosystem processes and characteristics (Telesetsky 2013). Indeed, achieving the specialized purposes may often require violation of the scientific characteristics of ecological restoration, thus raising concerns as to whether these programs are accomplishing ecological restoration at all.

Because they are often poorly conceived or undertaken in a landscape or environmental context that will not support the system (Figure 1), many mitigation projects have very limited objectives and fail to produce fully functioning ecosystems (Gebo and Brooks 2012; Bronner *et al.* 2013). While mitigation projects may comply with regulatory requirements, assessments of mitigation projects are increasingly revealing that these projects have resulted in inadequate ecological structure or function, indicating that the goal of "no net loss" of aquatic resources is not being met (Hossler *et al.* 2012; Palmer and Hondula 2014). Moreover, despite the EPA and USACE being aware of this problem (USACE/EPA 2008), compensatory mitigation inherently facilitates the redistribution and reconfiguration of ecosystems between areas of development and areas of wetland restoration (Womble and Doyle 2012), an ironic application of restoration ecology. For example, wetland losses often occur in populated regions yet wetland creation to mitigate for those losses often happens in distant regions where land costs are lower (BenDor *et al.* 2009).

Programs that focus on the conservation of endangered species are also not designed with ecological restoration as the primary objective – their goal is species recovery, not system recovery. In some cases, endangered species depend on habitat that is not native to the area, thereby causing a conflict between conservation of the species and restoration using historical or contemporary reference points for the ecosystem (Schlaepfer *et al.* 2011). In other cases, the scarcity of suitable habitat for a species might necessitate restoring a particular ecosystem state that must be perpetually managed to prevent natural succession (Scott *et al.* 2005).

The increasing focus on restoration as a way of maintaining ecosystem services (eg Water Resources Development Act Principles, Requirements and Guidelines; CEQ 2013, 2014) is yet another example where policy vagueness promotes confusion between ecological restoration and specialized goals. Restoration techniques may be used to create the biophysical conditions that underlie specific ecosystem services like carbon sequestration or nitrogen removal but not necessarily self-sustaining natural ecosystems (Palmer and Filoso 2009; Bullock *et al.* 2011). Furthermore, offset projects and other "payments for ecosystem services" programs create an incentive to use restoration techniques to produce these marketable services, which may unintentionally discourage comprehensive ecological restoration actions.

Other specialized programs that are increasingly being associated with ecological restoration are becoming the focus of scientific and policy debate. Most are responses to concerns over whether ecological restoration will be possible given changes in climate or land use. Three examples include "assisted colonization" (physically moving species to areas that appear to be transitioning into suitable habitat for those species; Gallagher *et al.* 2015); "facilitated migration" (managing areas deemed likely to provide future habitat for adaptively migrating species; McLachlan *et al.* 2007); and "restoring toward novel ecosystems" (broadening restoration goals to include human-altered ecosystems as the end point; Perring *et al.* 2013).

Policies concerning climate-change adaptation measures also typically emphasize the need to foster environmental resilience to protect human populations from floods, storms, and other destructive events. Ecological restoration has certainly been proposed as a means of improving ecosystem resilience (Harris *et al.* 2006), but so has the use of restoration techniques to create "green infrastructure" that will not be self-sustaining, such as dune systems and wave-mitigating marshes in exposed coastal regions (Magliocca *et al.* 2011). Projects with more limited objectives, such as slowing erosion or controlling stormwater flows, are also increasing in number. Although these may be labeled as restoration projects, in practice they are engineering projects that are informed to varying extents by ecological principles. Such infrastructure, while potentially valuable, is built to protect human populations or buildings or to mitigate uncontrolled storm flows but is not a restored, self-sustaining ecological system.

In summary, incorporating the term "restoration" into administrative laws and grouping together different types of efforts that are not fully consistent with the basic tenets of ecological restoration are at best contributing to confusion over what it means to restore a system and at worst facilitating the net loss of natural resources. The latter is of great concern because restoration-as-mitigation is being increasingly used to justify development and natural-resource extraction based on the unfounded assumption that restoration projects will guarantee the replacement of degraded or lost ecosystems (Palmer and Hondula 2014).

When projects are ecological restoration

We have outlined why it is critical to distinguish ecological restoration from other types of environmental intervention, but it is also important to address concerns that we are setting the "restoration" bar so high that few projects will qualify as ecological restoration. We argue that this is not the case. The key distinction between restoration and intervention projects is that ecological restoration projects: (1) take actions to remove the stressors causing the problem or to influence biophysical processes in order to correct the problem; (2) have a plan of action focused on restoring a system and its dynamics, including interactions between biota and processes; and (3) are located in landscape and environmental contexts in which the restored system can become self-sustaining over time. We offer a few examples of such projects across a spectrum of problems and levels of restoration actions (Figures 2 and 3). Suding *et al.* (2015) also provided useful examples of projects that do and do not qualify as ecological restoration efforts.

Some ecological restoration initiatives simply involve removing the stressor (eg preventing livestock from overgrazing pastureland or from moving through stream channels to obtain water). One riparian ecosystem project in Oregon documented recovery using historical and contemporary photographs coupled with field measurements (Figure 2). This project led to geomorphic recovery of the stream channel (so that it was no longer widened and deepened by erosion); regrowth of native grasses, sedges,

Figure 2. There are many examples of valid ecological restoration projects. In these, the source of degradation has been removed or actions have been taken to recover the ecological processes that support a self-sustaining community similar to one that existed historically or similar to least-disturbed contemporary communities. (a) A riparian restoration project site in Oregon resulted in an increase in the number of willow and aspen and a decrease in streambank erosion at most sites several decades following removal of livestock (adapted from Batchelor et al*. 2015); (b) highly eroded stream prior to restoration; (c) stream post-restoration.*

and forbs; recruitment of aspens; and an increase in bird diversity (Earnst *et al.* 2012; Batchelor *et al.* 2015). More complex restorations may necessitate recovering underlying biophysical processes that have been fundamentally altered for long periods of time. For example, reinstating wetland hydrological processes is the focus of many restoration projects on low-lying lands that were previously drained to provide rich soils for agricultural production (Figure 3). Initiatives in the Coastal Plain of the eastern US, for instance, have restored hydrological processes, native plants, and some biogeochemical processes (Denver *et al.* 2014; Yepsen *et al.* 2014).

The most difficult projects are often those in highly urbanized areas, but ecological restoration is still possible in these settings. For example, artificial wetlands and novel stormwater control designs are being used to restore tidal and non-tidal receiving waters. Mallin *et al.* (2012) demonstrated that a series of wetlands created upland of a waterway effectively reduced stormwater flows and pollutant fluxes from suburban developments, substantially improving water quality in the receiving creek. In that case, the wetlands represent environmental interventions that were implemented to restore the creek. Although more time and effort is required to fully restore the creek, local municipalities have developed plans to continue to address the problem using practices that help recover underlying watershed processes such as infiltration and nutrient processing. Many attempts at urban stream restoration have focused on the stream channel itself, but numerous recent studies have shown that this approach rarely results in ecological recovery; as such, more sustainable alternative methods are now being adopted (reviewed in Palmer *et al.* 2014). For example, actions to reduce peak stream flow and channel erosion in Nine Mile Creek in Pittsburgh, Pennsylvania, involved rerouting the channel, installing hydraulic structures in the stream, and regrading stream banks to reconnect the floodplain to the water (Bain *et al.* 2014). Over time, however, it became obvious that the current landscape context could not sustain this particular channel design project – multiple repairs were necessary as the channel eroded and degraded. Recognizing that restoring the stream required interventions in the surrounding landscape, a local non-profit, the Nine Mile Watershed Association, with input from the USACE, helped shift the focus from reach-scale interventions in the stream to watershed-wide actions, including the installation of rain gardens and rain barrels, tree plantings, and the replacement of impervious sidewalks with permeable ones.

Moving forward

We are not suggesting that all specialized programs are misguided and should not be pursued. Rather, their relation to, and difference from, ecological restoration needs to be clarified. The term "restoration" carries with it some "feel good" legitimacy that, when included in the text of statutes, regulations, and policies, masks the trade-offs and other constraints imposed by the specialized purposes of such programs. It would be more accurate to refer to "*mitigation* restoration", "*endangered species* restoration", "*ecosystem services* restoration", "*climate resilience* restoration", and so on. These terms would make the use of ecological restoration for specialized purposes explicit and signal the possibility that the goals of the specialized program might not always lead to what restoration ecology in its intended form would produce. Moreover, just as more coherence is needed for defining what qualifies as ecological restoration in its unconstrained form, the ways in which restoration is used within these limited contexts must be defined with far more precision in statutes, regulations, and implementation guidance. Local communities and other stakeholders in such projects should be made aware of the planned departure from full ecological restoration, so that they have a voice in the trade-offs that are inherent in such choices.

There are options for moving forward. Ideally, a national omnibus law would be developed, detailing the best practices or minimum standards of restoration and requiring

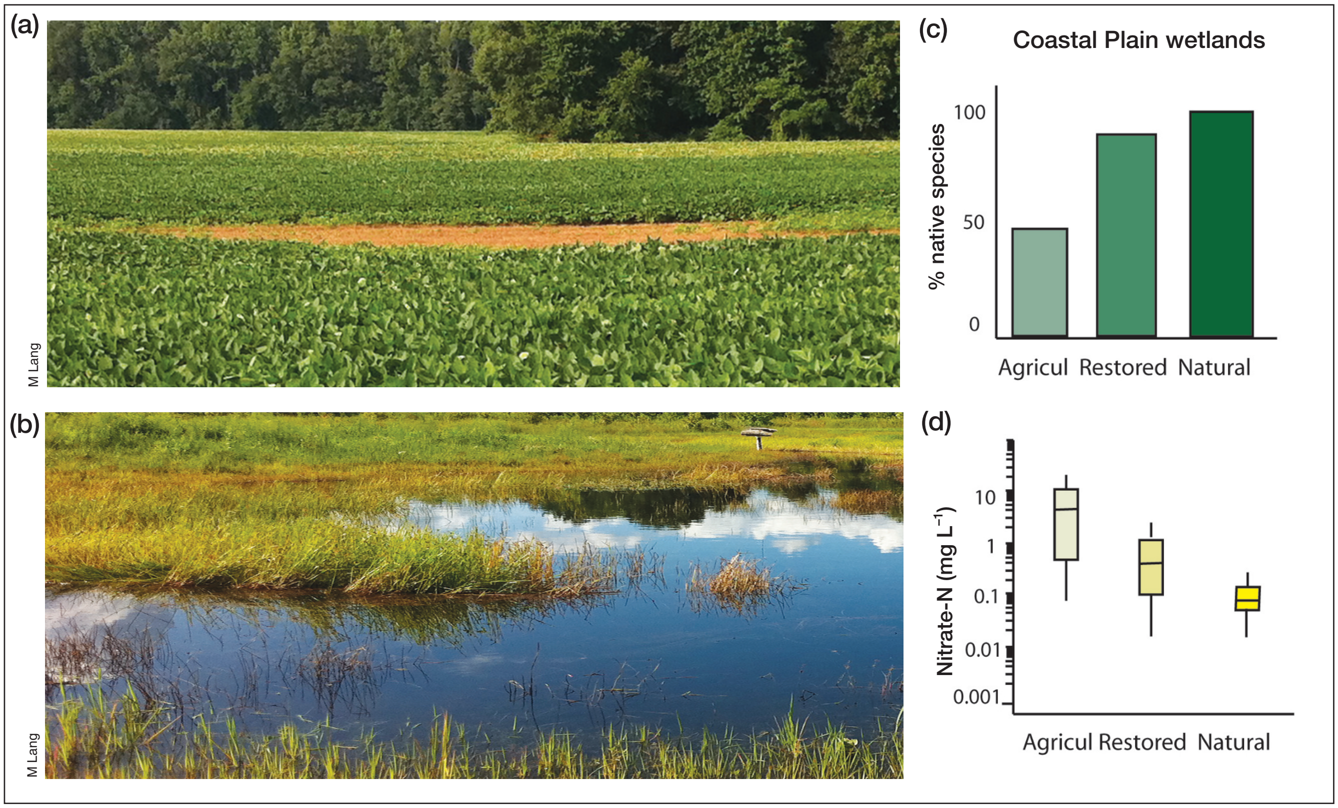

Figure 3. *Wetland areas in the Coastal Plain region of the US that have been converted to croplands (a) are being ecologically restored (b) by plugging drainage ditches or creating berms. While most projects are quite new, the US Department of Agriculture Conservation Effects Assessment Project (Brinson and Eckles 2011) is already documenting improvements in the percentage of native species (c) (Yepsen* et al. *2014) and dissolved nitrate levels (d) (Denver* et al. *2014). It is not clear whether the sites will reach the "natural", forested wetland state, but if not disturbed (eg by mowing) they appear to be self-sustaining.*

agencies using restoration for specific purposes to issue rules explaining how they do so. Agencies would work within the statutory terms to develop regulations and policies for restoration activities appropriate to their mandates, making clear when their interventions do not require true ecological restoration. However, given that the US Congress is unlikely to pass such a law, the White House Council on Environmental Quality could issue an omnibus restoration policy fulfilling much the same purpose. Alternatively, members of Congress could ask the US Government Accountability Office or the Congressional Research Service to survey the restoration practices of all federal agencies – their written policy and what they do in the field. This could then be used by a National Academy of Sciences/National Research Council (NRC) board or committee to outline best practices and minimum standards. In a 2001 report, the NRC emphasized the importance of restoring for self-sustainability in wetland restoration projects (NRC 2001); however, it has been over 20 years since the last comprehensive report on ecological restoration (NRC 1992). Since that time, there has been rapid growth in the number and types of projects that are implemented under the term "restoration", and many studies have questioned the methods that are employed and the extent to which projects are falling short of expectations. This information needs to reach managers and permitting agencies, and may even help to prompt policy changes. Such a report could also highlight what new information and research is needed to support potential policy changes. We believe that both the scientific and legal communities are eager to contribute to such an endeavor and that society cannot afford to wait.

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