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Editorial

Ecological restoration and ecological engineering: Complementary or indivisible?

A B S T R A C T

Ecological engineering and ecological restoration are distinct disciplines, both of which are urgently needed to reverse global environmental damage. Relative to ecological restoration, ecological engineering provides outcomes that are more predictable but with lower diversity. It also aims to provide higher functionality with respect to one or a few ecosystem services, relative to ecological restoration which aims at full, long-term recovery of lost ecosystem services. Ecological engineering generally incurs higher maintenance costs and provides lower values of natural capital than ecological restoration. In particular, we contend that "large scale restoration projects" include little restoration and should be recognized as "large scale rehabilitation programs" more aligned with ecological engineering principles and the overriding aim of restoring natural capital. Engineers and ecologists must work together and learn from each other if our work is to generate significant societal benefits.

In a recent editorial in *Ecological Engineering*, founder and editor, Bill Mitsch asked: "*When will ecologists learn engineering and engineers learn ecology?*" (Mitsch, 2014). Fundamental to this question is our concept of nature. Ecologists study nature to determine what it is and how it functions. Ecologists are also conservative in the sense that they are protective of "nature" and urge prudent management and use of land, water, and ecosystems in order to satisfy those human values that are predicated on naturalness in the environment. Ecological engineers' work, in contrast, consists in part of transforming nature to provide benefits pertaining to the provision of natural goods and services, such as flood control and providing clean water, remediation of contaminants, and erosion control. This basic difference in orientation and terms of reference creates a gap to cross in the search for mutual understanding.

Mitsch (2014:9) stated that ecological engineering has two goals, namely "*the restoration of ecosystems that have been substantially disturbed by human activities such as environmental pollution or land disturbance, and the development of new sustainable ecosystems that have both human and ecological value*." This statement of goals closely follows the definition of ecological engineering given by Mitsch and Jørgensen (2004:23) as "*the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both.*" These and similar statements by Mitsch over the years valiantly call for the restoration of disturbed ecosystems in a manner that unites ecologists and engineers in common cause. We applaud this effort; however, we advise that these definitions need revision to align with current concepts of ecological restoration if we seek mutual understanding. Terms like *design* and *sustainable*, for example, carry with them implications that impedes the dialog for which Mitsch has called. To understand why, requires a close look at ecological restoration.

1. What is ecological restoration?

"*Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed*" (SER, 2004). The tacit assumption in the early years of the development of modern ecological restoration was that assisted recovery would lead to reestablishing an ecosystem to the state of biodiversity and functioning that existed prior to its impairment. Sometimes this was possible, especially in stable, extra-tropical environments with relatively limited biodiversity, and particularly in ecosystems that could recover quickly to a pre-disturbance state, such as herbaceous marshes. This optimism was abetted by lingering allegiance to outdated concepts of climax communities and balance of nature. Ecologists have abandoned the ideal of truly recovering the past. They recognize that ecosystems are dynamic and life moves inexorably forward at a pace governed by flux, environmental instability, and the longevity of dominant organisms. This better-nuanced view of nature led ecologists to realize that an ecosystem was merely the temporal expression of biodiversity moving along an ecological trajectory over time. Ecological restoration may have seemed to be reconstructing ecosystems, but we now see that it is really about an interrupted ecological trajectory that we seek to reestablish. Historical continuity is what is being recovered (Clewell and Aronson, 2013a,b). The theoretical importance of recovering ecological trajectories is not a new concept in ecological restoration (Aronson et al., 1993); indeed it seems now to be on the way to becoming mainstream. International conventions (e.g., CBD, 2012), intergovernmental platforms (e.g., IPBES, 2013) and policy calls for massive action (e.g., IUCN, 2014) show that ecological restoration is now recognized as a global priority for biodiversity conservation, combatting desertification and land degradation, and

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limiting the impacts of anthropogenic climate change (Aronson and Alexander, 2013).

Interventions that are performed onsite to assist recovery are limited to those in only a few categories. Practitioners can ensure that:

- Desirable species are present and undesirable species are absent.
- The physical environment supports the desirable species.
- The characteristic biotic community structure is developing.
- Flows and exchanges of materials and organisms are occurring normally with the surrounding landscape.
- Threats in the surrounding landscape that may cause a recurrence of impairment have been removed insofar as possible.

An ecological reference determines species composition and structure, not as a fixed model, but rather as a guide to allow planning, action, monitoring, and evaluation. Efforts are made to include as many as possible of the pre-impairment species in the restoration process, because these were presumably co-adapted species that previously assembled to form a sustainable ecosystem. A pre-project baseline inventory determines the needs for physical site repair at the project site and adjustments to normalize exchanges with the surrounding landscape. Both the ecological reference and baseline inventory are critically important for planning project implementation, because they determine initial biodiversity of the restored ecosystem and specific efforts needed to repair the physical environment.

Once ecological processes have returned to normal levels of function, evidence of self-organization (or self-design to use Mitsch's term) will become evident, mainly in terms of plant growth and reproduction, and spontaneous recolonization by native biota. Ecological complexity will gradually manifest in terms of habitat diversity and niche diversification. The capacity for resilience to disturbance will increase, and the capacity for self-sustainability will develop commensurately with that of ecological reference ecosystems. These attributes emerge as manifestations of normal ecological processes and not directly from practitioner intervention.

An ecosystem is considered restored as soon as self-organization becomes evident and onsite project work by practitioners is no longer needed. Completion of a restoration project is similar to healing in the medical profession. A medic can set the bone in a leg so that it heals in the pre-break position. Upon becoming ambulatory the patient is considered healed. The initiation of self-organization in an ecosystem undergoing restoration would be equivalent to the time that the patient became healed.

Mitsch (2014:13) wrote, "*. . .engineering is a field devoted to removing uncertainty and controlling natural processes.*" Predictability of the outcome, control of ecosystem processes, and removal of doubt are not germane considerations to ecological restoration projects (Table 1). The intent of ecological restoration is to embrace uncertainty as one of greatest defining qualities of this enterprise. Future states of biodiversity and ecosystem dynamics will reflect the constraints and fluctuations of contemporary environmental and societal conditions to which the ecosystem in question must continually adjust (SER 2004:1).

2. Design, sustainability, and ecological engineering

The fundamental concept to engineering of design is problematic in respect to ecological restoration. Design implies a product. You design a building or bridge always with a final product in mind. You plant a garden or a tree farm with a crop as the intended product. A natural or semi-cultural ecosystem is not a product. Rather, it is the temporal expression of ceaseless ecological development. What is sustained is not a static ecosystem but instead a dynamic process. What we call an ecosystem is only a temporal manifestation of biodiversity generated by that process. When sustainability is understood from that perspective, only then can we expect to see ecologists and engineers fully appreciate each other and working together in synergy.

Mitsch revealed his understanding of this issue when he wrote about self-design: "*Ecosystem restoration, as currently practiced throughout the world, is done by practitioners who have little experience in design. . .and by engineers who do not appreciate the capabilities of ecosystems to self-design. . ..*" Self-design is the antithesis of design that is intended to produce an outcome by removing uncertainty and asserting control of natural processes.

Design in ecological restoration refers not to a product or outcome but instead to strategies and tactics for conduct of a restoration project. Will the restoration be performed with minimal assistance to foster natural regeneration? Or will it draw upon technological solutions with extensive site preparation, soil amendments, and dense plantings of nursery stock? Will restoration be conducted all at one time or will it be prolonged in phases to allow adaptive management? These are the sorts of questions that restoration ecologists consider with regard to design. To eliminate confusion, we strongly advise that design in the traditional engineering sense be deleted from definitions and discussion pertaining to ecological restoration.

The terms *sustainable* and *sustainability* also cause confusion in the way they are used in ecological engineering. Sustainability is an intangible ideal that defies verification. It can be assessed indirectly by comparing trends in recovery to local, intact reference ecosystems. Its assessment is further complicated in restored ecosystems that are located in fragmented natural areas where external management is needed to substitute for missing natural drivers on which sustainability depends. Pyrogenic ecosystems, particularly, require prescribed fires as surrogates for the much larger-scale fires that naturally ignited in unaltered landscapes. Constructed waterways may be needed as substitutes to maintain wetland hydrology. Such external management has become the norm, and the ideal of ever reaching natural sustainability fades accordingly.

3. Is ecological restoration a subset of ecological engineering?

Mitsch and Jørgensen (2004:24) viewed ecological engineering as an amalgam encompassing a large number of modalities that are applied to stimulate environmental recovery and improvement, including ecological restoration. In this regard, they considered ecological restoration as a subset of ecological engineering. We disagree: ecological restoration is a not a subset of anything else. Ecological engineering was introduced as an approach that substituted living organisms and products of biological origin for inert materials such as concrete and steel. This new approach proved effective for solving problems within the purview of traditional civil engineering. These services commonly cost less to install, operate and maintain than traditional civil engineering solutions. They were more energy efficient and were less interruptive and intrusive on landscapes. Ecological engineering did not introduce ecological restoration and "*. . .the restoration of ecosystems that have been substantially disturbed by human activities. . .*" (Mitsch, 2014:9). Ecological restoration has a long history (Jordan and Lubick, 2011) that goes back as far if not further than that of ecological engineering.

Ecological engineering is essentially problem-solving; its approach is technical and proactive rather than nurturing. The nurturing approach, which is used extensively in ecological restoration, relies insofar as possible on spontaneous recovery and on minimal interventions known as 'assisted natural regeneration.' The