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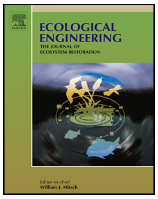

Restoration ecology: Ecological fidelity, restoration metrics, and a systems perspective

Michael P. Weinstein[a,*], Steven Y. Litvin[b], Justin M. Krebs[c]

[a] Center for Natural Resources Development and Protection, New Jersey Institute of Technology, 327 Martin Luther King Jr. Boulevard, Newark, NJ 07102, United States
[b] Hopkins Marine Station, Stanford University, Oceanview Blvd., Pacific Grove, CA 93950-3094, United States
[c] AKRF, Inc., 7250 Parkway Drive, Suite 210, Hanover, MD 21076, United States

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ABSTRACT

Although the importance of ecosystem services associated with estuarine wetlands and their functional linkages to other estuarine habitats have been increasingly recognized in the past 60 years, the approach to “restoration” and “rehabilitation” of degraded wetland habitats has largely lacked the application of systems thinking and scientific rigor; and has resulted in a “disconnect” between the science and practice of wetland restoration. Examples of coastal wetland restoration science are discussed in the context of wetland functions that promote secondary production, ecological fidelity and their “connectedness” to both adjacent waters and the coastal zone. A means to integrate restoration science and practice to inform policy, and the quantification of restored functions in a systems framework is also described in the context of a sample case history.

1. Introduction

Mankind’s activities in the Anthropocene have pushed the Earth system outside of its normal operating range into new equilibrium states (Steffen et al., 2005). Not only do many ecosystems differ in pattern and process from those in the past, but the ecosystem concept itself is becoming increasingly framed in the context of climate change, land use, invasive species, reduced biodiversity and other outcomes of human endeavors. These new ecosystem states, often less desirable, are described as “novel, no-analog, or emerging” states (Hobbs et al., 2009; Higgs, 2012). As a consequence, the challenges of ecosystem restoration and rehabilitation have reached new levels of complexity.

There are two broad themes addressed in this paper; first we distinguish between *restoration ecology*, the ‘science’ of restoring degraded habitats, and the broader inclusion of cultural aspects and practices in what we refer to as *ecological restoration* (Weinstein, 2007). In reality, the line between restoration ecology and practice is oftentimes “fuzzy” (Falk et al., 2006), but both approaches and their integration are critical for the future success of restoration science, and while there is no one single, fixed, “correct” restoration for any particular site, functional criteria can provide tight guidelines for success (Higgs, 1997). Secondly, we link the designs for wetland restoration to the consideration of linkages of the wetland to the estuary as a whole, including the coastal zone; i.e., wetlands should be viewed as interactive components of the broader mosaic of habitats that exchange materials and organisms and which together interactively support the secondary production of marine transients.

2. Restoration ecology: the emerging research paradigm

Although the importance of ecosystem services associated with estuarine wetlands has been increasingly recognized in the past 60 years, the approach to “restoration” and “rehabilitation” of degraded ecosystems has often lacked scientific rigor. The science of restoration ecology manages for change, fosters biodiversity and emphasizes the return of system functions, connectivity, and the production of goods and services to degraded ecosystems. But while “the time is ripe for basic researchers to ask if current ecological theory is adequate for establishing new principles of restoration ecology” Palmer et al. (1997) and Hildebrand et al. (2005) cautioned that “the incredible complexity of nature forces us to simplify the (complex landscapes) we study in order to develop theory and generalities by reducing them to understandable subsets”. Because

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* Corresponding author. Tel.: +1 973 309 2043.
E-mail addresses: mweinstein_fishguy@verizon.net (M.P. Weinstein), litvin@stanford.edu (S.Y. Litvin), jkrebs@akrf.com (J.M. Krebs).

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ecosystems are inherently dynamic and exhibit non-linearities and behavioral surprises, the ability to predict and manage restoration trajectories has been particularly vexing (Mitsch et al., 1998; Anand and Desrochers, 2004; Ruiz-Jaen and Aide, 2005). Hildebrand et al. (2005) assert further that realistic goals must include multiple scientifically defensible endpoints of functional equivalence. In defining these endpoints, ecologists are seeking new ways to assess acceptable levels of variability in restored ecosystems, most appropriately in a regional or landscape context and within some "bound of expectation" (White and Walker, 1997; Weinstein et al., 1997; SER, 2004; French, 2005). There are also questions related to community stability, resilience and persistence; all central to understanding/predicting whether a restored system will be self-sustaining. Additionally, individual metrics of restoration success must be better defined, quantified, integrated, and raised to levels compatible with measuring ecosystem functions, self-organization and ecological resilience.

Scientists generally agree that the evaluation of restored functions should include measures of *processes* such as primary or secondary production, but may also reflect considerations of biogeochemical cycling, food-web structure, food quality, habitat connectivity, biological interactions, including the presence of invasive species, refuge from predators, key-stone species, donor control (Polis and Strong, 1996; Weinstein et al., 2005), microhabitat structure, and access to resources. Many species exhibit complex life histories that place them in different parts of the landscape at different times, but their overall success may depend on the quality of specific habitats at critical bottlenecks in their life history. For example, marine transient finfish at mid-latitudes are characterized by life histories that invoke a "coastal conveyor belt" with adults spawning offshore and near estuaries, and young spending their first year of life in estuarine habitats including tidal wetlands (Weinstein, 1981; Deegan, 1983; Weinstein et al., 2009a). Young-of-year complete the cycle by accompanying the adults offshore during their autumn migration to overwintering areas. It is likely that the quality of the estuarine habitats, especially tidal wetlands at mid-latitudes is reflected in growth, condition and survival of young-of-the-year marine transients and is a critical aspect of their successful recruitment to the adult stage.

2.1. Ecological restoration

From a practical standpoint, the human dimensions of ecosystem restoration and rehabilitation place limits on the application of restoration ecology principles; especially ecological fidelity in restoration designs (Higgs, 1997). More than 35 years ago, Cairns et al. (1975) distinguished between the public perception of restoration practices and scientific knowledge: "the characteristics of restored ecosystems are bound by two general constraints, the publicly perceived restoration and the scientifically documented restoration. For example, recovery may be defined as restoration to usefulness as perceived by the users of the resource. This is significantly different than restoration to either the original structure or the original function (or both) as rigorously determined by scientific methodology." Cairns (1995) noted also that societal constraints place practical limits on the outcomes of restoration efforts.

Thus, restoration success comes in at least two fundamental forms, (1) projects that restore ecological fidelity and longevity (self-organizing traits) to sites through the application of best scientific principles; and (2) projects that rest on cultural foundations, restoring sites to some practical use as perceived by society. For some restoration efforts, what constitutes a "natural ecosystem" is being redefined in the context of the density of humans in the landscape and shifting baselines, but what we want to avoid are impressions of wetland restoration practices that are devoid of ecological fidelity like these examples:

> [Restoration may] *be seen as a sort of gardening with wild species in natural mosaics . . . an expensive self-indulgence for the upper classes, a New Age substitute for psychiatry* (Allen and Hoekstra, 1992). *It distracts intelligent and persuasive people from systematic initiatives* (Kirby, 1994) . . . *to many industrialists and global environmental negotiators . . . ecological restoration appears a fair and benign, Western middleclass, pastoral practice, the kind of activity that harms no one and fills in the gaps among the really big problems* (Higgs, 1997).

2.2. Integrating restoration ecology and ecological restoration

The challenge then is to build a stronger foundation for the science of restoration based on methods that go beyond simple structural criteria, or population parameters (e.g., catch per unit effort) to metrics of restored functions and/or processes. Habitats and whole ecosystems are being restored nationwide, but the fundamental question remains, what *kinds* of ecosystems are being restored? Previous restoration paradigms, e.g., those appearing in the national framework embodied in the US Clean Water Act, managed by the US Army Corps of Engineers, and overseen by federal "coordinating" agencies, have been woefully inadequate (Turner et al., 2001). A critical aspect of the integration process is to gain acceptance of the science (and the need for scientific rigor) by practitioners who will design and implement the projects. A concrete example of one such effort is found in Restore America's Estuaries (RAE), *Principles of Wetland Restoration*; derived through a partnership of scientists and practitioners (RAE, 2001; Weinstein et al., 2001).

Notwithstanding that processes/functions are difficult and rarely measured in restoration projects because of time/funding constraints restoration science must advance to a point where technology transfer of basic research becomes practical in the practitioner/resource manager's tool kit. Whether in the form of a "bound of expectation", "probabilistic laws" (Ehrenfeld, 2000) or other goal-setting paradigm, the asymptotic endpoint(s) of the restoration effort must be established early so that practitioners can answer the simple question: was the restoration project successful? The scientific basis for determining this success is currently, at best, "thin" (Henry and Amoros, 1995; Stanturf et al., 2001), and the "myths" that these and other authors refer to have been variously described (e.g., Cabin, 2007; Hildebrand et al., 2005). Zedler (2007) has gone so far as to challenge the very use of the term "success", a point well taken, but for the moment, we will simply note her suggestion for "abstinence" or "rendering opinions" when the term is used, and revert to the bad habit here. Because the scope of restoration science is so broad and encompasses such a wide range of ecosystems, we present a case study to describe how restoration science and practice can be integrated to better inform policy, stakeholders and decision makers. We focus on coastal wetland ecosystems and their role in supporting secondary production of marine and estuarine nekton and their forage base.

2.3. "Donor Control" and restoration planning

Marine transient species that are largely marine as adults, benefit from tidal salt marshes and their production *with or without directly occupying these habitats* (Litvin and Weinstein, 2003; Weinstein et al., 2005). Many are highly mobile, and tend to cross habitat boundaries in their quest for food and refuge. Species of interest include taxa of estuarine resident and marine transient species considered to be of "value" to mankind, but includes work