Marine Pollution Bulletin 64 (2012) 820–835

Contents lists available at SciVerse ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Developing multimetric indices for monitoring ecological restoration progress in salt marshes

O.C. Langman [a,*,1], J.A. Hale [a,1], C.D. Cormack [a,1], M.J. Risk [b], S.P. Madon [c,2]

[a] Pandion Technology Ltd., Suite #601, 6th Floor, 28th October Street, Limassol 4065, Cyprus
[b] PO Box 1195, Durham ON, Canada N0G 1R0
[c] CH2M HILL, Water Resources and Ecosystems Management, Ecosystem Planning and Restoration, 402 W. Broadway, Suite 1450, San Diego, CA 92101, USA

ARTICLE INFO

Keywords:
Multimetric index
Salt marsh
Ecological restoration
End states of restoration
Restoration trajectory
Adaptive management

ABSTRACT

Effective tools for monitoring the status of ecological restoration projects are critical for the management of restoration programs. Such tools must integrate disparate data comprised of multiple variables that describe restoration status, including the condition of environmental stressors, landscape connectivity, ecosystem resilience, and ecological structure and function, while communicating these concepts effectively to a wide range of stakeholders. In this paper we describe the process of constructing multimetric indices (MMIs) for monitoring restoration status for restoration projects currently underway on the eastern coast of Saudi Arabia. During this process, an initial suite of measurements is filtered for response and sensitivity to ecosystem stressors, eliminating measurements that provide little information and reducing future monitoring efforts. The retained measurements are rescaled into comparable domain metrics and assembled into MMIs. The MMIs are presented in terms of established restoration theories, including restoration trajectory and restoration endpoint targets.

1. Introduction

Degradation of aquatic ecosystems, primarily from anthropogenic activities, has led to major efforts to regenerate, rehabilitate, or convert ecosystems towards a more desirable configuration (National Research Council, 1992). The motivation behind restoration projects is the restoration of ecological services and functions, which impact a wide range of stakeholders beyond restoration scientists that will need to be informed of the progress of the project. Despite the large body of theory that supports the development and design of restoration projects, it has been pointed out (Jones and Schmitz, 2009; Reeves et al., 1991;Roni et al., 2003) that monitoring efforts have often proven inadequate to quantify physical and biological responses within the ecosystems being modified. Given this possibility of failure and the importance of communicating ecological information to stakeholders, monitoring programs need to play several roles, including: (1) integrating the scientific knowledge and theories behind the design of the project into the monitoring program to include the measurement of appropriate stressor and response variables, (2) developing and implementing an analytical framework that evaluates monitoring data to provide the pertinent information needed to adaptively manage the restoration to improve its chances of success, and (3) presenting the progress and condition of the restored ecosystem to the stake holders in a manner that is easily interpretable and understandable, yet based on valid scientific assessments.

1.1. Endpoints of restoration

The endpoints of restoration have been described in terms of community structure as well as supporting chemical, biological, and physical processes (National Research Council, 1992). Descriptions matching this level of detail for the desired state of remediation sites are rare, which has lead to the practice of having reference ecosystems provide the basis for both developing remediation methodology and evaluating the progress of an ecosystem restoration (Society for Ecological Restoration, 2004). While a reference system can be used as a model for a desirable outcome of restoration, the restored site will at best approximate the condition of the reference site due to spatial variability, however, slight, in the physical, chemical, and biological gradients forming the basis of the ecosystem processes. Further variability within a reference system emerges from the innate non-static nature of an ecosystem, across season variability, community-level evolution, or natural progression of the reference systems to new states (Duarte, 1991; Horne and Schneider, 1995; Palmer and Poff, 1997). Sadly, the desire to force an ecosystem into an overly specified state is common, and has resulted in restoration ‘failures’ that are, for the most part, functional ecosystems in their own right (Simenstad and Thom, 1996).

---

[*] Corresponding author. Tel.: +1 608 3207761; fax: +1 803 2546445.
E-mail address: owen.langman@gmail.com (O.C. Langman).
[1] Tel.: +1 803 5135649; fax: +1 803 2546445.
[2] Tel.: +1 619 6870120x37233.

0025-326X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2012.01.030

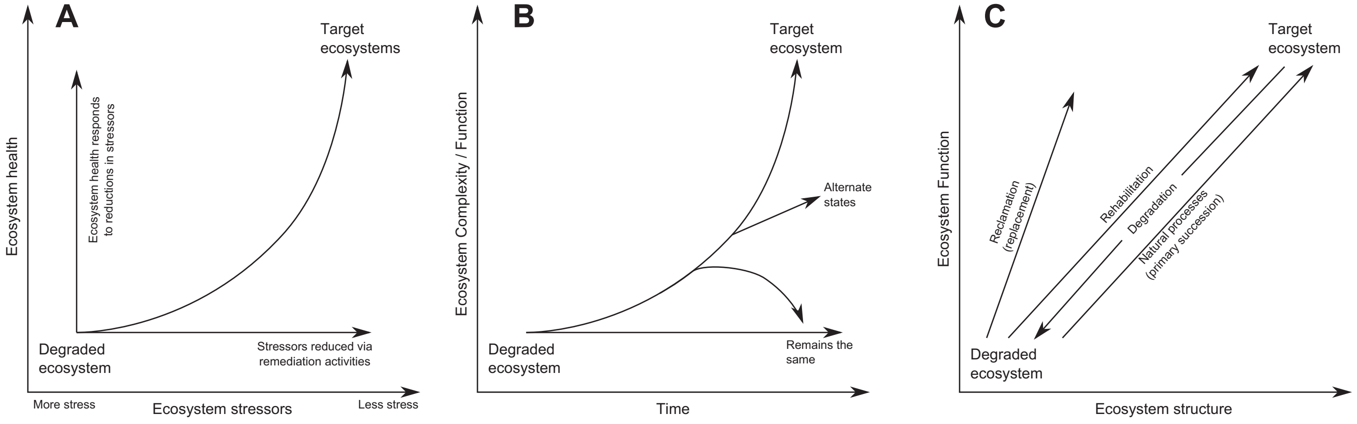

Fig. 1. Theoretical spaces that describe the response of an ecosystem to remediation. (A) An original space that assesses the response of ecosystem health to the reduction of stressors (B) A mapping of ecosystem complexity through time, redrawn from Hobbs and Mooney (1993) (C) Evaluating ecosystem function (biomass, nutrient content, cycling) against structure (species diversity, complexity), redrawn from Dobson et al. (1997).

1.2. Trajectory

Equally as important as the restoration endpoint is the progression from degraded to a restored ecosystem. Numerous conceptual models for the progression of a restoration site through time have been proposed (Dobson et al., 1997; Hobbs and Mooney, 1993; Hughes et al., 2005; Magnuson et al., 1980), with the term "trajectory" being used to describe the hypothetical pathway traversed during the restoration progress (Fig. 1).The multiple interpretations of restoration trajectory are based on which ecosystem attributes (e.g., ecosystem health, structure, and function) are being tracked (Fig. 1) indicating the difficulty of consolidating the requirements of ecological restoration even at a conceptual level. As a reflection of this, the theoretical spaces leave trajectories simplified, indicating a general direction and approximate endpoint. Practical applications of the trajectory concept have largely involved developing multiple trajectories for individual parameters, often indicator species, used to represent restoration status. The inherent variability of single parameters, for example, over stressor gradients and temporal/spatial scales, however, often results in inconclusive representation of restoration trajectory (Odum et al., 1995;Zedler and Callaway, 1999), and aggregating parameters into a single trajectory has proven difficult (Society for Ecological Restoration, 2004). An ideal trajectory would integrate disparate data that describe site condition (and thus restoration status), and provide information that may be used to adaptively manage the restoration project.

1.3. Adaptive management

Without a regular assessment of restoration status supported by a well-developed monitoring program, a restoration site may follow a trajectory different from the desired outcome. While our understanding of succession is continually improving, knowledge of the current state of an ecosystem and the stresses that it will face during restoration will never be complete, leading to difficulty in making accurate predictions of site evolution over the duration of the restoration project. The proposed solution to this problem is to monitor the restoration status and to nudge the system toward the desired trajectory and adaptively manage it if a significant deviation is detected. According to Shreffler et al. (1995) , this concept is not new, but there are few examples in the literature that indicate the principle is being used. Possible reasons for this include insufficient funding for additional manipulation, lack of clear resolutions to the problems, or a lack of supporting data to drive the management. In the latter case, the decision to re-engage in the manipulation of the restoration site can be improved by providing managers with a broader dataset that describes ecosystem status, and by extension, the range of problems that can occur during restoration.

Actually describing the concepts of trajectory, restoration endpoints, and adaptive management within the context of a monitoring program remains a difficult task. Recent attempts at describing ecosystem status have moved in two distinct directions: (1) identifying organisms that can be used to integrate multiple signals from the ecosystem (indicator species); or (2) by collecting large amounts of data to produce community descriptors. Indicator species have been developed as the corner stone of monitoring programs (Metcalfe et al., 1984;Reynoldson, 1987). Monitoring programs based on indicator species are particularly attractive because acquiring the data is often time- and cost-effective. Several common assumptions about the relationship of indicator species with the greater community have proven unreliable, however, such as the idea that high species richness or habitat diversity is correlated with the occurrence of rare species (Pearson and Cassola, 1992), or that associations between species remain similar across a given habitat (Niemi et al., 1997). When evaluating ecosystem status, particularly in restoration projects where the successional trajectory can be short-cut through plantings, species introductions, and other modifications, the lack of reliability of these relationships reduces the value of using just species–community relationships for evaluating the condition of the ecosystem.

Complex systems need to be described using a framework of many parameters, although this task can overwhelm the researcher with data. Important parameters for ecosystems include elements of structure, function, landscape connectivity, and resilience to perturbations, all of which must be addressed to evaluate the status of a restoration. Karr (1981) introduced a multimetric index (MMI) to represent elements of biological condition in a variety of different systems. Karr's work stemmed from the use of water quality data as a surrogate for biotic assessment, in cases when biological condition could not adequately be characterized. Until then, water quality was primarily monitored chemically and physically by the EPA and other monitoring institutions, but despite extensive monitoring and management programs water quality continued to deteriorate (Davis and Simon, 1989; EPA, 1987; Karr, 1981). This resulted from not only having excess chemical data that were swamping managers, but from a lack of data on the biological processes working on the ecosystems (Karr, 1981). Since its introduction as a method of monitoring biotic condition