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Review

A review of methodologies and success indicators for coastal wetland restoration

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ABSTRACT

Coastal wetlands are considered to be amongst the most productive ecosystems and can provide invaluable ecological services. However, coastal wetlands are listed amongst the most threatened ecosystems suffering from anthropogenic activities. The loss or degradation of coastal wetlands has drawn a high level of attention to wetland restoration. Improvement of the structure and function of degraded, damaged and destroyed wetlands may be achieved through ecological restoration. Large numbers of restoration projects have been conducted worldwide based on different restoration goals and different methods. It is undoubtedly important to evaluate whether coastal wetland restoration is successful. However, coastal wetland restoration assessment has become challenging because of current disagreement on definitions and concepts of restoration evaluation. We reviewed the methodology of coastal wetland restoration and criteria for success evaluation, and then summarized the issues for current wetland restoration and success evaluation based on literature review. Moreover, we used an estuarine wetland affected by urbanization as a sample to demonstrate how to establish a success indicator system for guiding wetland restoration and evaluating the success of wetland restoration.

Contents

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1. Introduction

Coastal wetlands are formed adjacent to the margins of continents by tidal forces, fresh water inputs, sediment transport and biota (MEA, 2005; Wolanski, 2007; Barbier, 2013). Coastal wetlands are considered to be amongst the most productive ecosystems and can provide invaluable services such as storm buffering, protection from windstorm and shore erosion, fishery production, water purification and biodiversity maintenance (Alongi, 2008; Costanza et al., 2008; Newton et al., 2012; Barbier, 2013). However, coastal wetlands are also severely threatened, and considered to be the ecosystem most sensitive to global sea-level rise (Morris et al., 2002; Wingard and Lorenz, 2014). Although the coastal zone only cover 4% of the earth total land area, this narrow region provides harbors for nearly one-third of the world's human population, and also provides critical habitat for organisms such as migratory waterbirds (MEA, 2005; Alfaro and Clara, 2007; Fitzsimmons et al., 2012). However, coastal wetlands have been suffering from serious degradation, alteration or loss due to intense anthropogenic activities (i.e., wetland reclamation, pollution and drainage) (Lemly et al., 2000; Newton et al., 2012; Cvetkovic and Chow-Fraser, 2011), and thus, coastal wetlands are listed amongst the most heavily damaged of natural ecosystems worldwide (Barbier et al., 2011). It is estimated that approximately 50% of salt marshes, 35% of mangroves and 29% of seagrasses have been lost or degraded due to environmental stresses and human disturbances (Wolanski, 2007; Valiela et al., 2009; Barbier et al., 2011). In China, 23% of freshwater swamps, 16% of lakes, 15% of rivers and 51% of coastal wetlands (in terms of the total area) have disappeared over the past 50 years, due to reclamation and urbanization (An et al., 2007). The loss or degradation of coastal wetlands could lead to biological invasions, poor water quality, decreased coastal protection from hurricanes and storms, fishery losses and threats to the ecological safety of coastal areas (Costanza et al., 2008; Koch et al., 2009; Newton et al., 2012; Barbier, 2013). Moreover, the deterioration of coastal wetlands causes loss in carbon storage, which could accelerate regional climate change (DeLaune and White, 2012). Therefore, there is an urgent need to develop and improve ecological restoration methods to rehabilitate or restore degraded coastal wetlands.

Since the 1960s, much more attention has been paid to natural ecosystem degradation, and great efforts have been made to restore and recreate those damaged ecosystems (Daily, 1995; the Secretariat of the Convention on Biological Diversity, 2010). Currently, the interest in ecological restoration is strengthened as restoration can mitigate climate change and biodiversity loss (Nilsson and Aradóttir, 2013). Starting in the 1990s, wetland restoration and re-creation became a "hotspot" in the ecological research fields (Thormann and Bayley, 1997; Visser et al., 1999; Zedler and Kercher, 2005). The US government enforced the regulatory policy of 'no net loss' of wetlands, combined with a focus on wetlands banking to ensure minimum impacts on wetlands. The importance of this issue is exemplified by the fact that coastal wetlands restoration is regarded as part of British Petroleum's (BP) obligation due to the regulations of the Oil Pollution Act of 1990 (Barbier, 2011). Coastal wetland restoration and creation have also been listed as important themes in recent international wetlands and ecological conferences (MEA, 2005).

In China, the first wetland restoration projects started in the early 1990s. More than 200 programs with costs in excess of 20.7 billion dollars (USD) have been aided financially to protect current natural wetlands, restore damaged wetlands and create wetlands that have been lost (SFAC, 2000, 2005). The "863" Environmental Action Plan funded 36 projects during 2000–2005, which aimed at restoring water quality of natural lakes and rivers, and improving pollution purification capacity of urban wetlands (SEPAC, 2005). Another 53 large programs with a total funding amount of more than 100 billion dollars will be conducted to restore and create an additional 14,000 km^2 of wetlands by 2030 (An et al., 2007).

The objectives of this paper are (1) to review methodologies, techniques and success indicators for coastal wetland restoration and restoration assessment; (2) to summarize the current issues in coastal wetland restoration and provide insight for coastal wetland restoration projects; and (3) to provide an example of establishing a success indicator system which would help guide reasonable restoration assessment.

2. General mechanisms and techniques for coastal wetland restoration

Since water, biota and soil are three basic elements of a wetland, restoration or creation of wetlands are centered on these three constituents. Hydrology restoration or re-establishment is indispensable and considered the fundamental objective of restoration projects. Furthermore, the interaction between three elements should be highlighted to reveal key processes that lead to degradation.

A wetland is considered an organic network ecosystem with multi levels or various interacting components. Once the interaction between different components of wetlands is determined, including the integrity of wetland functions, mechanisms responsible for the degradation of pivotal components can be clarified. Meanwhile, ecosystem services should be listed as an important target and constraint for restoration (Zedler and Kercher, 2005). Spatial–temporal heterogeneity, structural coordination, and functional integrity should be coupled to establish different scenarios and to identify thresholds to reveal the restoration mechanism of wetlands.

The changes in the structures and functions of wetland ecosystems can be analyzed by multi-scenario simulations (Turner et al., 2000), thus identifying the key processes, indicators and threshold values. The coupling mechanisms between hydrology, vegetation and habitat in wetland ecosystems have to be clarified to develop wetland restoration techniques. Soil seed bank restoration techniques for degraded wetlands have been developed based on the analysis of the interaction between vegetation and the seed bank (Bossuyt and Honnay, 2008). Habitat replacement and compensation is another important wetland restoration technique which focused on the development of functional groups (Quigley and Harper, 2006). Ecological water supplement restoration techniques include an integrated multi-scale and multi-stage approach developed by combining different restoration targets and stages with ecological water demands of wetlands (Zhuo et al., 2013). Scenario analysis and model simulation under different management and regulation modes have been applied to evaluate the effectiveness of regional wetland restoration and alleviate regional potential risk led by various restoration schemes (McIntire et al., 2007; Cui et al., 2009a,b).

Perrow and Davy (2002) pointed that ecological restoration included restoration, rehabilitation, remediation and reclamation. Wetland restoration refers to the return of wetland from a disturbed or altered status caused by anthropogenic activities to a pristine status (Mitsch and Gosselink, 2007; Jarzemsky et al., 2013). Unlike rehabilitation (the partial or full replacement of the original ecosystem's structure and function), ecological restoration implies the return of the degraded ecosystem to its pristine condition (Ellison, 2000). In addition, the use of creation, restoration and (or) enhancement to compensate wetland losses is defined as wetland mitigation (Kentula, 2000). To avoid vague and imprecise language used in the literature and for simplicity, the distinction between the above concepts will not be addressed here.