Estuarine, Coastal and Shelf Science 181 (2016) 100–113

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Landscape metrics applied to formerly reclaimed saltmarshes: A tool to evaluate ecosystem services?

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ARTICLE INFO

Article history:
Received 16 September 2015
Received in revised form
19 April 2016
Accepted 21 August 2016
Available online 24 August 2016

Keywords:
Ecosystem services
Landscape metrics
Saltmarsh typologies
PCA
Coastal defence index

ABSTRACT

Analyses of saltmarsh ecosystem services have been particularly focused on the capacity of mitigating climate change effects to cope with rising sea levels and concerning flood management. Nevertheless, ecosystem stability is vital for accurate service delivery, but land-use changes and coastal erosion are affecting saltmarshes. This provides the background for one of the primary arguments for protecting saltmarshes. Landscape metrics were selected according to shape, complexity, and connectivity parameters, and added to average elevation and distance to the coast, for two years - 1972 and 2010. We developed an equation that measures coastal protection, taking into account the results of PCA and the percentage of explained variation of each component (coastal defence index: ES_CoastDef). Three saltmarshes located in the Algarve region, Portugal, were selected to apply the coastal defence index. Individual patches were analysed according to saltmarsh typologies. Results revealed that every saltmarsh decreased its coastal defence from 1972 to 2010; changes in shape and connectivity metrics affect mostly the index performance. In 1972, natural saltmarshes offered a better coastal defence than the other typologies, but in 2010 formerly reclaimed saltmarshes comprised higher values of coastal defence. Positive evolutions in terms of reclaimed saltmarshes have enabled them to provide coastal defence ecosystem services. Thus, through this index it is possible to outline target coastal defence parameters and design strategies for their conservation and consider ecological restoration.

1. Introduction

Ecosystem services have been broadly discussed since Costanza et al. (1997) and De Groot et al. (2002) first introduced the concept of biodiversity economics into the discourse of resource protection and sustainability. When considering giving nature a price, opinions are divided: some authors are for an economic approach (Costanza et al., 2008; Barbier et al., 2011), while others emphasise the need to combine different knowledge bases to understand ecosystem services (Wallace, 2007; Fisher and Turner, 2008). Nevertheless, Costanza et al. (1997) and M.A. (2005) have defined service typologies and managed to differentiate services and functions and to aggregate them in wider sub-ecosystems. This groundwork was the start of a growing body of literature on ecosystem services theories, valuation systems, and application frameworks: economic theory of benefit estimation (English et al., 2009), valuation methods of ecosystem services (King and Mazzotta, 2000); dollar-based ecosystem valuation methods (Costanza et al., 1997; De Groot et al., 2012); ecosystem value estimates – benefit-cost (Loon-Steensma and Vellinga, 2013). All agree that difficulties arise when decisions must be made towards protecting and managing natural resources. Trade-offs underlying allocation ecosystem functions after damage or disturbance are closely related to ecosystem recovery options and to current concerns regarding ecosystem response to climate change triggers (Feagin et al., 2010) (in which saltmarshes, as coastal fringing ecosystems, are included, especially when considering rising sea levels).

Saltmarsh ecosystem services are largely described in the

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http://dx.doi.org/10.1016/j.ecss.2016.08.020
0272-7714/

literature: Simas et al. (2001), Möller et al. (2001), Möller (2006), Gedan and Bertness (2010), and Feagin et al. (2010) analyze the capacity of saltmarshes to mitigate effects resulting from climate change. The capability of saltmarshes to cope with sea level rise and their relation with vegetation allow for different successional and topographic states and therefore absorb various flood levels (Morris et al., 2002; Möller and Spencer, 2002; Feagin, 2008; Watson and Byrne, 2009; Reeve and Karunarathna, 2009; Kim et al., 2011); their natural capacity of regulating climate and plague control (barrier effect) (Gedan et al., 2009; Spencer and Harvey, 2012); nutrient cycling (Deegan et al., 2012); carbon and nitrogen sequestration (Chmura et al., 2003; Caçador et al., 2007; Reboreda et al., 2008; Mattheus et al., 2010); vegetation attributes for cattle (grazing) (Milotić et al., 2010) and cuisine (*Salicornia* pickles) (Gedan et al., 2009); water storage, refugee habitat for fish, crustacean and birds (English et al., 2009), recreational and cultural services, such as bird watching, cannoning and fishing (M.A. 2005).

Land-use changes, sea level rise and coastal erosion (among other factors) are affecting several wetland ecosystems particularly saltmarshes, and one of the primary arguments for protecting saltmarshes is related to preserving and enhancing the quantity and the quality of the lost saltmarsh ecosystem services (Gedan et al., 2009).

The consistency characteristics of an ecosystem are essential for accurate ecosystem service delivery: features such as elevation, extension and stability in an ecosystem are necessary conditions for the regulating and maintenance of coastal protection services (Liquete et al., 2013), such as wave reduction or flood protection (Loon-Steensma and Vellinga, 2013). Saltmarshes have a natural capacity of mitigating sea storms and other extreme climate events, such as tsunamis (Simas et al., 2001; Gedan and Bertness, 2010; Kim et al., 2011). Costanza et al. (2008), Barbier et al. (2011), and Roebeling et al. (2013) demonstrate that this attribute results from the extension, exposition and orientation of the coastal system within the coastline. The work of Möller and Spencer (2002) added the level of consolidation of floristic communities (stability and maturity) to the list of coastal wetland attributes, particularly when it comes to saltmarshes, to cope with sea level rise and extreme coastal events. Additionally, a model developed by Brampton (1992) and used by Möller et al. (2001) indicates a reduction by 40% of wave height when crossing an 80 m width whose elevation is below sea level (de-embanked saltmarshes) and patches covered with vegetation. These attributes have contributed to absorb the first impact of wave overtopping and reduce the effect of wave propagation, due to the roughness provided by micro-topographic changes and vegetation cover. The results of this study were applied to evaluate the trade-offs of artificial coastal protection (jetties) in the UK, and supported advances in recreation for coastal defence (Möller, 2006).

When ecosystems are artificially modified to increase a particular service (i.e. coastal defence) ecosystem services are manipulated, but how can these enhancements be evaluated when reference values of those services are lacking? The same occurs when saltmarshes recover without human intervention (abandonment, de-embankment, old reclamations), how can ecosystem services be evaluated? This requires an analysis of which ecosystem services can be provided by a natural saltmarsh and how these can be evaluated (Costanza et al., 1997, 2014; De Groot et al., 2002; 2010; M.A. 2005).

Moreover, the reclamation process of formerly reclaimed saltmarshes is framed by the work of Bonis et al. (2005), Barkowski et al. (2009), Garbutt and Wolters (2008), Almeida et al. (2014) and linked with recovery theory. The concepts of recovery and restoration used in this paper are from Elliott et al. (2007): for restoration to occur (active process – human intervention) on a degraded ecosystem, it implies discarding mitigation, which will result in an improved habitat or in a new ecosystem, which can then be enhanced in the future; conversely, starting also with a degraded ecosystem, recovery is a passive process, without human intervention, that will result in a new ecosystem. Regarding ecosystem services, Elliott et al. (2007) refer that despite the pre-impact state being frequently unknown, functions, structure, goods, and carrying capacity of the ecosystems may not return to their original state.

Syrbe and Walz (2012) brought important insights regarding spatial indicators for the assessment of ecosystem services, however we believe that some innovative methodological approaches are needed, combining the spatial definition of ecosystem services using landscape metrics in order to inform restoration planning. In this context, reclaimed and naturally recovered saltmarshes (Almeida et al., 2014) were the starting point for this exercise that aims to apply landscape metrics to ecosystem service assessments. In this context, metrics with a coastal protection bias were selected to develop a coastal defence index, based on saltmarsh attributes. The aim is to understand whether landscape metrics could be a tool applied to saltmarsh passive recovery in order to assess ecosystem service delivery, specifically the coastal protection attribute of saltmarshes. The index developed to measure the coastal protection offered by a specific saltmarsh is of broad application – it can be replicated in other saltmarshes, regardless of their biogeographic region. The proposed set of data, materials and methods (explained in the third section) are of international application, provided geographic information on the targeted saltmarshes is available. If this condition is verified, it will be possible to combine this tool with ecological restoration strategies, thus reinforcing saltmarsh ecosystem services. It would also provide saltmarshes with the capacity of positively responding to future anthropogenic disturbances or to cope with rising sea levels.

2. Landscape metrics and ecosystem services

Müller and Burhard (2012) discuss the informative power of ecosystem services, mentioning that they have the potential to assess the state of ecosystems, acting as indicators. In this context, landscape metrics will be used to establish quantitative boundaries to inform ecosystem services, with the aim of moving from an economic perspective to effective policies of ecosystem diagnosis, to help decision-making and to support recovery and protection measures (Müller and Burhard, 2012). Landscape metrics measure and describe spatial structures such as individual patches, patch types or land mosaics, providing information on landscape composition and configuration (Leitão et al., 2006). Composition and configuration are the two main domains in landscape metrics: the former (composition) refers to the diversity and abundance of patch types, missing spatial character or arrangement, whereas the latter (configuration) has a strong spatial basis, informing also about position and orientation. These two properties are interactive and complementary and not mutually exclusive (Leitão et al., 2006). The same authors demonstrate the application of landscape metrics to five different phases of the planning process: (1. Focus, 2. Analysis) to further inform the planning system (3. Diagnosis, 4. Prognosis) on ecosystem recovery processes (5. Synthesis). This justifies the interaction of landscape metrics applied to a formerly reclaimed saltmarsh.

2.1. Complexity

Leitão et al. (2006) state that size and shape metrics can be used as proxy information about patch ecological and functional features. These two metrics are also informative on the amount of