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The "ReDune" index (Restoration of coastal Dunes Index) to assess the need and viability of coastal dune restoration

Debora Lithgow [a,*], M. Luisa Martínez [a,b], Juan B. Gallego-Fernández [c]

[a] Red de Ecología Funcional, Instituto de Ecología AC, Xalapa, México
[b] Instituto de Ingeniería, UNAM, Mexico City, Mexico
[c] Departamento de Biología Vegetal y Ecología, Universidad de Sevilla, Seville, Spain

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ABSTRACT

Overpopulation and deficient management of the worlds coastlines have seriously degraded beaches and coastal dunes, which are environments that provide valuable ecosystem services to society. The need to restore these ecosystems is increasingly urgent; however, this is a complex task since variables that differ widely (i.e. ecological, geomorphological and socio-economic) must all be taken into consideration. The present study proposes an index in the form of a weighted checklist named the "ReDune" Index (Restoration of coastal Dunes). This index allows decision makers and non-specialized professionals with some level of understanding of coastal dynamics to decide whether coastal dunes (foredunes) require and can be restored. Furthermore, in cases where more than one coastal dune system is to be evaluated, the index can distinguish which are in the most urgent need of restoration. The index consists of four sections: the first evaluates the degree of perturbation. The second determines the presence of endogenous and exogenous stress factors that may compromise the long-term stability of the restoration. The third section is focused on highlighting the abiotic and biotic elements that may facilitate restoration. Finally, the fourth section contributes to the identification of interests related to the conservation of the site and the provision of ecosystem services. The index was tested on 31 locations along the Gulf of Mexico, with differing sedimentary, ecological and human pressure characteristics and clearly distinguished between locations where restoration is urgent from those where it is not. This index can be applied on any foredune.

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1. Introduction

Continuous population growth along the coasts produces an increasing human impact and, consequently, degradation or loss of coastal ecosystems (Coverdale et al., 2013; DINAS-COAST, 2006; Halpern et al., 2008). Due to their high vulnerability (Martínez et al., 2013a; Nordstrom, 2008), sandy beaches and coastal dunes are among the ecosystems likely to be most threatened and damaged (Barbier et al., 2011; Ketchum, 1972; Nordstrom, 2008). Typically, human-related impacts on coastal dunes alter natural dynamics and processes; eliminate topographic variability; fragment, degrade or eliminate habitats; affect biodiversity (by increasing, decreasing or substituting species) (De Luca et al., 2011; Faggi and Dadon, 2011; Martínez et al., 2006, 2013b; Nordstrom, 2000) and disrupt the provision of ecosystem services (Mendoza-González et al., 2012). As a result, actions of restoration on coastal dunes are increasingly necessary.

In general, coastal dune restoration has not been addressed as frequently as is needed. Evidence of this can be seen in the relatively reduced number of peer-reviewed literature focused on this topic (Lithgow et al., 2013a). Of these, a comparatively higher number of restoration and rehabilitation efforts have taken place on urban coasts (Nordstrom, 2008; Nordstrom and Jackson, 2013) than on non-urban sites. Both, however, are still incipient although there are an increasing number of sandy coasts that require restoration (Martínez et al., 2013a,b). Several problems arise regarding restoration actions: (a) the difficulty of choosing where restoration actions are most needed; (b) uncertainty regarding where these actions will have a higher probability of success; and (c) poor financial support. Moreover, decisions concerning restoration actions must be made rapidly and in a standardized manner and these should be multidisciplinary. They must be rapid so that restoration actions can be implemented efficiently; standardization facilitates direct comparison among sites; and a multidisciplinary approach considers the range of

* Corresponding author. Tel.: +52 228 842 1800 Ext. 4215.
E-mail address: debora.lithgow@gmail.com (D. Lithgow).

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different factors (i.e. ecological, geomorphological and socio-economic) that are implicit in the management and restoration of natural ecosystems.

A multidisciplinary approach can be challenging and complicated. It requires the understanding of complex information and, ideally, the approach must be easily understood by experts from different disciplines. In this sense, several indices have been created so that non-specialists can use and integrate multidisciplinary approaches (Araújo and da Costa, 2008; Botero et al., 2014; Cooper and McLaughlin, 1997; McLachlan et al., 2013). In particular, different studies of coastal dunes have used multidisciplinary indices to address the complexity of beaches and coastal dunes, in terms of vulnerability (García-Mora et al., 2001; Martínez et al., 2006; Muñoz-Vallés et al., 2011 Williams et al., 2001) and the impact of tourism (Leatherman, 1997; Phillips and House, 2009). Cervantes and Espejel (2008) designed the Integrated Beach Value Index, which is useful for comparing tourist beaches and considers attributes such as biophysical features, litter and socio-economic indicators. Similarly, Micallef et al. (2011) used the BARE (Bathing Area Registration and Evaluation) technique to rate five beach parameters (safety, water quality, facilities, scenery and litter). Additionally, McLachlan et al. (2013) designed two indexes to evaluate physical, ecological and socio-economic factors of sandy beaches. The first index determines beach conservation value and the second measures the recreation potential of a location. By combining these two indices, a beach can be classified as suitable for intensive recreation, or primarily for conservation, or for mixed use. To our knowledge, however, there are no multidisciplinary indices that deal with the many aspects that need to be considered in coastal dune restoration efforts and that help to decide between three management interventions: restoration, rehabilitation and conservation.

The goal of this study was therefore to develop a checklist-based tool that would facilitate the decision-making process in coastal dune restoration. Specifically, from all dune types that have been described (Hesp, 1999), we focused on foredunes. Foredunes run parallel to the coastline and, on prograding coasts, foredune fields can be formed over decades or centuries. When this occurs, they show different degrees of stabilization, with the oldest foredunes occurring furthest from the coastline. In this study we focused only on the first and more recent foredunes that are located at the back of the beach and that remain relatively mobile. These dunes are the ones most affected by human activities.

We considered the variables identified by Lithgow et al. (2013b) as important to coastal dune restoration and used these to identify

Table 1
Elements with a positive influence on foredunes, divided into subcriteria and indicators.

Positive elements				Units
Criteria	Subcriteria	Variables	Variable description	
Facilitators	Abiotic elements	Sediment transport towards the foredune	Dune systems are generated from the sand on the beach	Evidence of sediment movement (qualitative): Low (non-buried vegetation), Medium (presence of sand on leaf surfaces), High (buried vegetation)
		Width of dry beach	Evidence of sufficient sediment supply	Beach width (m)
		Aeolic dynamics	Wind speed and direction determine dune formation	Presence or absence of minimum wind speed: 5 m/s)
		Shoreline orientation/ waves	Necessary for sediment transportation towards the beach and foredune	Orientation relative to prevailing wind and type of wave (spilling, plunging or surging breaker)
		Grain size	When sand grains are sufficiently small, they can be transported by the wind. Adequate sediment supply is fundamental for dune building	Grain size of the beach and foredune (qualitative or quantitative if possible): fine sand (grain size: 0.063–0.2 mm) diameter similar to icing sugar or flour; medium sand (grain size: 0.2–0.63 mm) diameter similar to granulate table sugar; coarse sand (grain size: 0.63–2.0 mm) diameter similar to unrefined brown sugar
	Biotic elements	Relative length of foredune	Provides evidence of local fragmentation	% of intact foredune
		Native species and dune builders	These are necessary for recovery of natural vegetation and further dune development	Presence/absence
		Pioneer species	Sand accumulates around pioneer species thus forming embryo dunes on the beach	Presence/absence
		Sources of propagules	Propagules from the same geographic region should be used for revegetation	Distance to the nearest source (km)
Elements that are useful for prioritization	Conservation	Endemic species	Ecological and evolutionary importance for conservation. Conservation of threatened psammophytes	Presence/absence
		High priority species	High priority species attract public interest and financial investment	Presence/absence
		Nearby protected areas	Important as potential sources of propagules	Distance to nearest protected area (km)
	Ecosystem services	Protection from storms and hurricanes	Protection is important given the increasing impact of storms and hurricanes in terms of damage to infrastructure and loss of human lives	Presence of infrastructure, cultural or economic interests at risk
		Hedonic	The scenic beauty of the beaches and shorelines has been widely recognized	More natural is perceived as more beautiful. The presence of hotels and large numbers of visitors are considered as a negative factor
		Recreation	Tourism is the largest industry in the world and beaches are the preferred destination	Distance from touristic sites other than the study site (km)
		Cultural heritage	Beaches and dunes have been used for millennia. There are important anthropological sites near or at the beach	Distance from cultural sites

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