



Ecological research questions to inform policy and the management of sandy beaches



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ARTICLE INFO

Article history:

Received 7 December 2016

Received in revised form

4 July 2017

Accepted 26 July 2017

Keywords:

Ocean shores

Pressures

Research questions

Policy

Management

Environmental goals

ABSTRACT

Sandy beach ecosystems have various ecocentric and anthropocentric values. These values are under multiple, increasing pressures from diverse human activities and, in particular, from the consequences of climate-change. The conservation of these values requires evidence-based policy formulation and management strategies that address societal goals such as those set by the United Nations (2012). Here, we use these goals, pressures, knowledge gaps and our combined judgement to nominate important policy- and management-orientated research questions. These are grouped under five broad topics: natural condition; protecting ecosystem health; conservation of biodiversity; sustaining ecosystem goods and services; and climate change. The last is particularly important since it threatens both services to society and the ecological integrity of beach ecosystems at great spatial and temporal scales. Further, humans are likely to respond to climate change in the urban coastal zone with large-scale engineering projects (e.g., nourishment, seawalls) which will have substantial ecological effects. The resolution of these questions should inform evidence-based policies and strategies to manage the pressures faced by ocean beaches.

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1. Introduction

Earth's ecosystems are being degraded by numerous anthropogenic pressures (McCauley et al., 2015) that threaten the sustained wellbeing of humans and other species. This situation calls for appropriate policy setting and management strategies that are informed, *inter alia*, by reliable ecological knowledge, but this is often inadequate or absent (Teck et al., 2010; UNEP, 2014). This failing often applies to sandy beaches (Dugan et al., 2010) where research is limited to few countries and small research teams (Nel et al., 2014). Consequently, despite a developing literature

addressing anthropogenic pressures and management (e.g., Defeo et al., 2009; McLachlan et al., 2013; Harris et al., 2014a,b; 2015; Schlacher et al., 2014), there are major knowledge gaps ranging from basic biology (e.g., taxonomy and life history; Petracco et al., 2014) to mechanistic ecological understanding (e.g., “a lack of empirical models describing the key beach processes” (Harris et al., 2014a, p.1)) and “significant disciplinary and interdisciplinary gaps remain that limit further conceptual advances and understanding” (Nel et al., 2014, p.8).

This neglect of beaches is significant because sandy shores dominate the world's coastlines (Bird, 1996) and provide numerous anthropocentric services such as recreation and coastal protection (Schlacher et al., 2008; Arkema et al., 2013). Further, beaches provide habitat for numerous species, including some with a high public profile (e.g., birds, turtles), some that are very abundant (Jones et al., 1991; Kennedy and Jacoby, 1999) and some that are endemic (Harris et al., 2014a). Unfortunately, these values are threatened by various anthropogenic pressures (Defeo et al., 2009;

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Jones, 2012; Schlacher et al., 2007, 2014). Pressures associated with climate change are of particular concern since unconsolidated sand makes beach ecosystems especially vulnerable to erosion and recession caused by sea-level rise and intensified storms (IPCC, 2014).

A first step in generating the knowledge needed to better manage beach ecosystems is to identify the research questions relevant to policy and management as has been done for other marine ecosystems (e.g., Parsons et al., 2014; Birchenough et al., 2015). Ideally, these questions would encompass both theory and empiricism, yielding general mechanistic explanations/principles that allow extrapolation and prediction in applied circumstances. The need to identify questions for sandy-beach ecosystems has been recognised by Schlacher et al. (2008) who included a preliminary set of research questions in a paper of broad scope. Given the developing appreciation of the ecological values, services and vulnerability of beaches, and the consequent need for evidence-based policy and management, it seemed appropriate to update and expand on these questions.

Thus, we propose tractable questions whose resolution would inform the policy-setting and management strategies needed to sustain ecological structures, processes and services. We hope this paper will guide researchers interested in policy and management, and granting bodies who set funding priorities. Of course, the latter will depend on local context.

We restrict coverage to the intertidal zone of beach ecosystems since this is often the most neglected component (Schlacher et al., 2008). Nonetheless, we acknowledge that intertidal beaches have close ecological linkages with contiguous subtidal and dune ecosystems (McLachlan and Brown, 2006; Dugan et al., 2011; Schlacher et al., 2015; Liebowitz et al., 2016) that are also under anthropogenic pressures. Moreover, these linkages have implications for the spatial scale of management.

2. Societal goals

Setting goals necessarily precedes the formulation of policies and management strategies. Existing beach management goals usually prioritise an anthropocentric “hazards and playgrounds” philosophy that seeks to maximise recreational benefits and protect societal assets (James, 2000; Maguire et al., 2011). However, given the increasing environmental recognition of coastal pressures, it is important to also adopt goals addressing the conservation of biodiversity (used here to mean variation in structure at genetic, species and habitat levels) and ecosystem function, i.e., goals that incorporate both anthropocentric and ecocentric ethics (Harris et al., 2014a, 2014b).

Such ethics are incorporated into the high-level goals for marine ecosystems set by the United Nations (2012), i.e., “to protect, and restore, the health, productivity and resilience of oceans and marine ecosystems, and to maintain their biodiversity, enabling their conservation and sustainable use for present and future generations.” Similar general goals have been set for coastal zones (e.g., Protocol on Integrated Coastal Zone Management in the Mediterranean, 2009; Office of Ocean and Coastal Resource Management, 2014). We consider that these general goals are appropriate for beach ecosystems. More specific objectives should be dictated by local context and pressures (e.g., beach nourishment, grooming). These are amenable to scientific research, and questions can be cast as testable hypotheses. The relative importance of goals/objectives will vary geographically since beaches differ greatly in their human use, ecological condition and legislative requirements for conservation.

3. Research questions to inform policy and management

The questions (Box 1) are grouped under five topics relevant to policy and management. The first topic (“Natural Condition”) provides the ecological context in which environmental changes are measured and impacts assessed. The other four topics contain questions with more direct management application. Their choice was guided by the above U.N. goals, existing knowledge gaps, and utility for managers. As well, questions should address reasonable spatial and temporal scales and they should permit testable hypotheses and realistic experimental designs (Sutherland et al., 2009). The topics/questions are not in order of priority and can be adapted for local contexts.

4. Discussion

4.1. Natural condition

The description of natural condition has management implications for several reasons. First, it provides baseline knowledge, including ranges of natural variation at different scales (e.g., Cooke et al., 2014), that informs conservation targets (e.g., Harris et al., 2014b). Second, such baselines can serve as references to assess cumulative degradation, to detect environmental impacts and to estimate their magnitude (e.g., Borja et al., 2012). Third, sustaining services requires an understanding of natural variability (Lester et al., 2010; Pinto et al., 2013). Finally, the detection of natural patterns is the first step in proposing and testing hypotheses of cause and effect, these enabling extrapolation in space and time and the prediction of ecological structure and function in the absence of human stress. In general, far more attention has been paid to spatial patterns (see Defeo et al., 2017 for a recent example) compared with temporal patterns which remain poorly studied.

A major beach hypothesis asserts the primacy of physical control of macrofaunal assemblage structure (reviewed in McLachlan and Brown, 2006; Lastra et al., 2006). Physical control implies the autecological hypothesis (Noy-Meir, 1979) which has been applied to sandy beach biota by McLachlan (1990). This hypothesis makes predictions concerning the inter-specific effects of invasive species, post-disturbance recovery, and the effects of climate change. Consequently, the autecological hypothesis is non-trivial in the beach management context but, since it has been challenged for dissipative beaches (Defeo et al., 2003; Ortega-Cisneros et al., 2017), it deserves further investigation.

The natural condition of interstitial meiofaunal and microbial biota (Cooke et al., 2014) is an area of particular ignorance. This matters because interstitial assemblages are species rich and they mineralize organic matter and recycle nutrients (reviewed in McLachlan and Brown, 2006), processes that contribute to the primary productivity of the surf zone (Odebrecht et al., 2014). Unfortunately, we know little about these functional processes or whether shifts in assemblage structure will affect them as can happen in estuaries (Kristensen et al., 2014).

Other functional questions involve habitat stability. What effect, if any, do the biota have on the erodibility of sand grains? While a stabilization function seems most unlikely for sparsely-populated reflective beaches, it may be a factor in dissipative beaches because of their smaller particles and richer biota. Such biogenic stabilization appears to be present in sandflats (Spears, 2008) and may become important if climate change exacerbates erosion. Alternatively, bioturbation may enhance the erodibility of beaches.

While trophic links are relatively well known (Dugan et al., 2011; Odebrecht et al., 2014), life-history studies are rare (Petacco et al., 2014). This matters because knowledge of life histories informs decisions about the spatial scale of conservation

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