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BIODIVERSITY RESEARCH

Sandy beaches at the brink

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ABSTRACT

Sandy beaches line most of the world's oceans and are highly valued by society: more people use sandy beaches than any other type of shore. While the economic and social values of beaches are generally regarded as paramount, sandy shores also have special ecological features and contain a distinctive biodiversity that is generally not recognized. These unique ecosystems are facing escalating anthropogenic pressures, chiefly from rapacious coastal development, direct human uses — mainly associated with recreation — and rising sea levels. Beaches are increasingly becoming trapped in a 'coastal squeeze' between burgeoning human populations from the land and the effects of global climate change from the sea. Society's interventions (e.g. shoreline armouring, beach nourishment) to combat changes in beach environments, such as erosion and shoreline retreat, can result in severe ecological impacts and loss of biodiversity at local scales, but are predicted also to have cumulative large-scale consequences worldwide. Because of the scale of this problem, the continued existence of beaches as functional ecosystems is likely to depend on direct conservation efforts. Conservation, in turn, will have to increasingly draw on a consolidated body of ecological theory for these ecosystems. Although this body of theory has yet to be fully developed, we identify here a number of critical research directions that are required to progress coastal management and conservation of sandy beach ecosystems.

Keywords

Sandy beaches, human impacts, coastal conservation, biodiversity, global change.

INTRODUCTION

The world's open coastlines are dominated by sandy beaches (Bascom, 1980), which are highly valued by society (Whitmarsh *et al.*, 1999; Parsons & Powell, 2001). Because they are the prime sites for human recreation, beaches underpin many coastal economies around the world (Klein *et al.*, 2004); more people use sandy beaches than any other type of seashore. But beaches are not just piles of sand, they support a range of under-appreciated biodiversity. A single beach can harbour several hundred species of invertebrates when the smaller forms (i.e. the interstitial micro- and meiofauna) are included in diversity surveys (Armonies & Reise, 2000). Beaches also provide unique ecological services, such as filtration of large volumes of seawater, not covered by any other ecosystem (McLachlan & Brown, 2006). They recycle nutrients (McLachlan *et al.*, 1985; McLachlan, 1989; Kotwicki *et al.*, 2005) support coastal fisheries (McLachlan *et al.*, 1996) and provide critical habitats (nesting and foraging sites) for endangered species such as turtles and birds (Burger, 1991; Rumbold *et al.*, 2001).

The intrinsic ecological values and functions of beaches are often perceived as secondary to their economic value. A possible reason is that the study of beach ecology is only now emerging as a theory-driven discipline. Several broad principles in beach ecology have recently been articulated (Defeo & Gómez, 2005; Defeo & McLachlan, 2005; McLachlan & Dorvlo, 2005; Scapini, 2006); these clearly emphasize the unique features of beaches. Importantly, drivers and ecological governing principles on sandy beaches differ markedly from those for other coastal ecosystems such as rocky shores and tidal wetlands. For example, sandy beach animals display a range of unique adaptations to these highly dynamic, three-dimensional environments, including mobility and burrowing abilities, rhythmicity in their behaviour, advanced sensory mechanisms and orientation, and plasticity (Brown & McLachlan, 1990; Brown, 1996; Scapini *et al.*, 1997). Similarly, the composition, diversity, and abundance of faunal communities on beaches are generally thought to be more strongly controlled by physical factors (e.g. wave climates, sediment properties) than by the biological interactions that act so strongly as an organizing force in other intertidal ecosystems (McLachlan *et al.*, 1993; McLachlan & Dorvlo, 2005).

PRESSURES

Globally, burgeoning population growth in coastal areas is placing escalating pressures on sandy beaches at unprecedented scales

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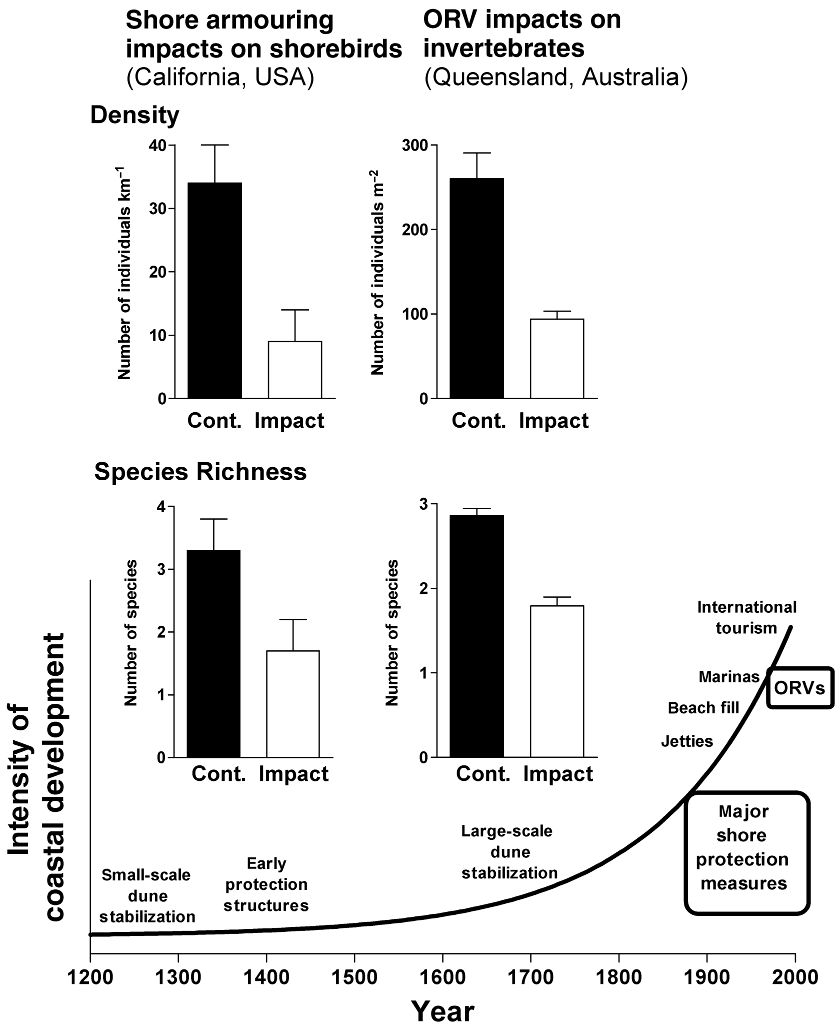

Figure 1 Ecological impacts of human activities on sandy beach biota illustrated by declines in abundance and species richness of birds on beaches with coastal defence structures, and benthic invertebrates on beaches subjected to heavy traffic by recreational off-road vehicles (ORVs). Bottom panel depicts a generalized trajectory of human modifications to soft coasts (modified from Nordstrom, 2000). Source data for shorebird impacts are from Jenny Dugan and David Hubbard (University California, USA) and from Thomas Schlacher (University Sunshine Coast, Australia) for beach invertebrates.

and amplitudes (Brown & McLachlan, 2002). Beaches are trapped in a 'coastal squeeze' between the impacts of urbanization on the terrestrial side and manifestations of climate change at sea. While unconstrained, beaches are resilient, changing shape and extent naturally in response to storms and variations in wave climate and currents. However, human modifications of the coastal zone severely limit this flexibility (Nordstrom, 2000).

Exacerbating this impact are human-induced alterations to coastal sediment supply and transport processes (Komar, 1998), as well as climate change-induced sea level rise and increased storminess (Slott *et al.*, 2006). Together, these stressors drive the global trend of beach erosion (Bird, 2000), with the result that coastlines are generally migrating inland. Because this brings beaches into conflict with human infrastructure, the mere threat of coastal erosion is enough to elicit a management response. Although ideally, this would entail natural retreat, removing man-made structures to accommodate the dynamism of the shore, this is generally not possible. In such cases, coastal authorities intervene more actively using either 'soft' engineering solutions (nourishment) or 'hard' armouring of the shoreline. The ecological consequences of engineering activities on beaches can be substantial at local scales (Fig. 1), and include the loss of biodiversity, productivity, and critical habitats as well as modifications of the subtidal zone which is an important recruitment zone for many sandy beach animals (Peterson & Bishop, 2005; Dugan & Hubbard, 2006; Peterson *et al.*, 2006; Speybroeck *et al.*, 2006).

Because natural shoreline retreat is today constrained along most developed coastlines by human infrastructures, we can predict future compression and loss of critical coastal ecosystems and habitats including not only dunes (Feagin *et al.*, 2005), but also functional beaches themselves. In addition to erosion and engineering, human activities are also impacting beaches directly (Table 1, Fig. 1). For example, increasing demands on beaches for recreation are highly detrimental in cases of heavy and inappropriate uses such as off-road vehicles driven on beaches (Fig. 1; Williams *et al.*, 2004; Schlacher & Thompson, in press).

RESEARCH NEEDS

The world's sandy beaches are iconic assets to society, but escalating threats to these systems pose formidable conservation challenges. Treating beaches as if they were simply piles of sand devoid of life places at risk the immense ecological values of sandy beaches (McLachlan & Brown, 2006). Although these ecological values of

Table 1 Key anthropogenic pressures on sandy beaches.

Key pressure	Reference(s)
Climate change and sea level rise	Feagin *et al.* (2005); Cowell *et al.* (2006); Harley *et al.* (2006)
Coastal infrastructure and development	Nordstrom (2000); Scapini (2002)
Shoreline armouring and erosion	Beentjes *et al.* (2006); Dugan & Hubbard (2006)
Beach nourishment	Peterson *et al.* (2000, 2006); Speybroeck *et al.* (2006)
Resource exploitation	
Fisheries	Defeo & de Alava (1995); McLachlan *et al.* (1996); Schoeman *et al.* (2000)
Mining/sand extraction	McLachlan (1996); Simmons (2005)
Pollution	
Chemical (oil spills)	de la Huz *et al.* (2005); Junoy *et al.* (2005)
Litter	Derraik (2002)
Freshwater discharge (quality and quantity)	Lercari & Defeo (1999); Lercari *et al.* (2002)
Grooming and cleaning	Llewellyn & Shackley (1996); Dugan *et al.* (2003)
Recreation and tourism	de Ruyck *et al.* (1997); Davenport & Davenport (2006)
Human trampling	Rickard *et al.* (1994); Fanini *et al.* (2005); Gheskiere *et al.* (2005)
Off-road vehicles (ORVs)	Godfrey & Godfrey (1980); Williams *et al.* (2004); Schlacher & Thompson (in press)
Beach and dune camping	Hockings & Twyford (1997)
Wildlife disturbance	Burger (1991); Parris *et al.* (2002); Thomas *et al.* (2003)
Light pollution	Salmon (2003); Bird *et al.* (2004)

Human perturbations affect sandy beaches both directly (e.g. habitat destruction, overfishing, off-road vehicles) and indirectly (e.g. human-induced climate change resulting in sea level rise and beach erosion). Impacts can also be interactive or additive, and act as either press or pulse disturbances over a wide range of spatial and temporal scales.

beaches are publicly less recognized than their social and economic equivalents, their loss could have large ramifications in the form of irreversible damage to crucial ecosystem functions (e.g. water filtration, nutrient recycling), loss of biodiversity, and destruction of critical habitats for endangered species.

To conserve the irreplaceable biodiversity and ecosystem features of sandy beaches, coastal management will have to progressively incorporate ecological aspects of beaches, which in turn requires sound ecological science. Although the fundamental principles of beach ecology are starting to become integrated into a coherent framework (Defeo & McLachlan, 2005), management responses require better predictive capabilities about the ecological ramifications of human activities and perturbations (Table 1, Fig. 1), than are currently available for many situations.

The limits of our scientific understanding of how sandy beaches respond ecologically to the plethora of human threats are fast emerging as crucial impediments for the conservation of these threatened ecosystems. A number of broad, non-exclusive research directions are therefore considered critical to address these gaps:

1 The identification, quantification, and economic valuation of vital ecosystem services provided by beaches.

2 The responses of beach ecosystems to the intensification of erosion and disturbance regimes and to human interventions that seek to counteract shoreline change and beach erosion.

3 The ecological consequences, including impacts on ecosystem services, of human activities, such as recreation, extractive use, and pollution, that directly impact beaches.

4 The functional relationships between drivers of the physical environment (e.g. wave regimes, sediment properties), organism transport, and the structure and function of beach ecosystems.

5 The implications of habitat loss and fragmentation as well as weakened linkages across critical ecotones and habitats for the conservation of sandy beach biodiversity, including endangered vertebrates such as turtles.

6 The effects of cumulative impacts from multiple stressors and disturbances operating at increasingly larger spatial scales and greater frequencies on the structure, function, and recovery dynamics of sandy beach ecosystems.

The scope of this list emphasizes the urgency of expanding research efforts on these threatened ecosystems. Interdisciplinary and innovative approaches as well as increased public outreach will be required to address the conservation crisis facing the world's sandy beaches.

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