SANDY BEACH BIOLOGICAL RESEARCH – IMPORTANT QUESTIONS FOR KNOWLEDGE AND MANAGEMENT.

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Abstract

Sandy beaches are under increasing pressure from human activities. The effects of climate change are especially important, with increased storminess and sea-level rise predicted to accelerate erosion and leading to changes in temperature, pH and hydrology all of which are likely to have biological effects. Additionally, human interventions to address erosion (eg, large-scale beach nourishment and shore armouring in urban areas) are likely to negatively affect beach ecosystems. To date, most management has focussed on the 'hazards and playgrounds' aspects of beaches to the detriment of understanding and valuing beaches and dunes as linked, unique and biodiverse ecosystems. Beaches are not abiotic deserts. On the contrary, they provide habitat for hundreds of buried microbial and invertebrate species that are critical in processing organic matter and forming the base of food webs culminating in fishes, shorebirds and raptors at the dune interface. Beaches also form irreplaceable habitats for iconic sea turtles and other vertebrates. To conserve the full range of ecosystem services provided by beaches, appropriate policy must be established and managers will require robust ecological information to inform their strategies. Unfortunately, less is known about the biology of beach ecosystems and their response to pressures than for other coastal ecosystems. Starting with a discussion about the nature of ecosystem health, resilience, and ecosystem-based adaptive management, this paper discusses the kinds of pressures that are most important, identifies some priority management-orientated questions and discusses a case study concerning beach nourishment. Some current obstacles are briefly discussed and some directions that may be profitable are suggested.

1. Introduction

Anthropogenic pressures on coastal ecosystems are now recognised as serious and likely to be exacerbated as growth in both economies and populations continue (Planet Under Pressure Conference, 2012). Indeed human influences on Earth are so large that the present epoch is now being called the Anthropocene (Steffen *et al*., 2012). There are even fears of large state changes in the biosphere (Barnosky *et al*., 2012). Clearly there is an urgent need for effective, science-based management to maintain both biodiversity and life-support for humans in the form of ecosystem goods and services. In response, biologists have proposed various research questions and agendas eg., a general ecological research agenda to promote a sustainable biosphere (Lubchenco *et al*., 1991), research areas relating to policy (Sutherland *et al*.,2006), conservation (Sutherland *et al*., 2009), environmental management (Morton *et al*., 2009) and ecosystem services (Nicholson *et al*., 2009). However, none of these exercises focused on sandy beaches/dune ecosystems despite their importance and vulnerability, especially to the various pressues of climate change (Jones, 2012, Schlacher *et al*., in press).

Sandy beaches are extensive ecosystems comprising 50-60% of the world's exposed shores (Bird, 1996). It is accepted that sandy beach/dune systems are valuable since they provide numerous goods and services, particularly recreational amenity and the protection of the heavily-populated coastal zone and its societal assets (Klein *et al*., 2004, Blackwell, 2007, Schlacher *et al*., 2008). In terms of scientific knowledge, much is known about beach geomorphology/ sedimentology and their interactions with erosive and depositional forces. This knowledge is used by coastal managers to protect both recreational amenity and societal assets and to predict the degree of coastal inundation that may result from global warming. However, beaches are not just sand. They also provide habitat for not only hundreds of plant and animal species, most being small and buried within the sand, but also iconic species such as marine turtles and birds of prey (McLachlan and Brown, 2006). Thus, beaches have irreplaceable anthropocentric and ecocentric values.

Unfortunately, beach/dune ecosystems are increasingly subject to coastal squeeze between the pressures arising from human activities on the terrestrial side and physico-chemical changes engendered by climate change on the marine side (Defeo *et al*., 2009, Jones, 2012). The vulnerability of the beach habitat is largely dependent on the rates of sea-level rise, coastal erosion, and the frequency of extreme events (Voice *et al*., 2006). Reduced sediment supply from impounded rivers is also a factor (Sherman *et al.,* 2002). On this basis, together with the biological effects of climate stresses and the dependencies on vulnerable adjacent systems, beaches are clearly "especially vulnerable" (CSIRO, 2002). Indeed, dunes and beachfronts were described as "vital areas" that would be lost through climate change or experience dysfunction (Cocks and Crossland, 1991).

Consequently, there is an increasing demand for management to protect and restore the ecological structures, functions and values of beaches. However, the efficacy of any active management in this regard is hindered by the lack of an effective policy management framework (James, 2000). Such a framework would benefit from a sound, scientific knowledge of social-ecological systems including beach biology. But beach biology is poorly studied (Fairweather, 1990, Dugan *et al*., 2010) and beach management is largely limited to non-biological "hazards and playgrounds" aspects (James, 2000). This denies beaches the protection accorded to other ecosystems (Dugan *et al*., 2010). Indeed, it could be argued that beach ecosystems should receive priority attention since they are especially vulnerable to various aspects of climate change.

Given that research funds are limited, it is important to identify the major knowledge gaps and the priority, policy-relevant questions whose resolution would inform scientifically-based management for both anthropocentric utility and ecocentric ecosystem health. This paper briefly discusses the concepts of ecosystem health, resilience, ecosystem-based and adaptive management and identifies the kinds of pressures that are most important to beaches. In particular, priority management-orientated questions and related research are identified.

2. Ecosystem Health

The term 'ecosystem health' (EH) is now commonly used in both managerial and scientific contexts and warrants a place in a prominent scientific encyclopedia (Calow et al., 1998).

Given that society desires ecosystems to be healthy, a prime question is "what does EH mean?" Although there is agreement that EH refers to the condition of ecosystems, their structures, functions and processes and the evolutionary potential of component populations, its meaning is imprecise. For example, different definitions emphasise stability, sustainability, resilience (Haskell et al., 1992), unimpeded trajectory to climax state (Ulanowicz, 1992), vitality, flourishing condition (Karr, 1996), good condition (Norris and Hawkins, 2000), vigour, organisation and resilience (Rapport et al., 1998) or naturalness or similarity to pristine condition (Schofield and Davies, 1996).

While many may believe that naturalness is a key criterion for EH, it is important to recognize that many natural ecosystems do not exist in a static state but exhibit much variation in space and time (Morrisey *et al*., 1992a, b). For example, large natural disturbances can decimate the biota (Jaramillo *et al.,* 2012) but recovery may occur. Are both the decimated state and the recovered state equally healthy? This situation has particular relevance to any health assessment of beaches because they experience large disturbances, both natural (eg, storms) and anthropogenic (eg, nourishment) and the state of the biotic assemblage can vary greatly as a result.

While the term "ecological health" is useful as a shorthand umbrella term with communication value, it cannot be measured unambiguously. Consequently, its limits as an operational term in any particular situation should be recognized. Scientific attempts to measure EH should be tailored to the context (eg, a nourished beach) and use appropriate measurable response variables describing assemblage structure and/or function.

3. Resilience

Closely related to EH is ecological resilience, defined as 'returning to the reference state (or dynamic) after a temporary disturbance' (Grimm and Wissel, 1997, p.323). It is one of the components of stability, the others being constancy (staying essentially unchanged) and persistence (persistence through time of an ecological system). Unfortunately, these terms are plagued by ambiguities (Grimm and Wissel, 1997). Ecological resilience is used here to incorporate the concepts of recovery and resistance since these are issues of management interest. Resilience can be considered at the level of habitat, ecological assemblage (both structure and function) and at the population/individual level where there are questions of tolerance, acclimation and evoloutionary adaptation.

In general, resilience is probably enhanced by maintaining both biodiversity (to promote adaptation) and multiple examples of each habitat type (to provide insurance and colonists following impacts). In this context, biodiversity operates at both the genetic diversity and species diversity levels. Large populations are likely to have greater total genetic diversity than small populations and therefore would be capable of greater adaptation to some pressures eg, falling oceanic pH. Of course, this would only succeed if the rate of adaptation matched the rate of environmental change. Concerning species diversity, a full complement of species is likely to confer greater redundancy in terms of ecosystem functioning than an impoverished ecosystem (Naeem, 1998). If so, system functioning would be more reliable in the face of pressures/stresses that reduce species diversity. As well, minimizing the number of stresses operating simultaneously would probably aid resilience. On beaches, the integrity of the sediment budget is of prime concern to the resilience of the physical habitat and the biotic assemblage (Bird, 1996).

4. Management

Management strategies should be directed towards achieving defined intervention goals. These beach management goals should also ensure that ecological values, health and resilance are addressed in any management scoping study and resultant implementation and monitoring programme(s). General ecological goals relate to ecosystem services, human pressures and environmental impact assessment (EIA), monitoring and biodiversity conservation. For beach ecosystems, we suggest that high-level management goals should also include a) the maintenance and restoration of the full range of ecosystem structures, functions and services provided by the interlinked surf-beach-dune ecosystems, including conservation of critical habitats, threatened species, and biological diversity , and b) the incorporation of ecological criteria into social-ecological thinking to enhance holistic, systems management.

In general, the maintenance of ecological structure and function requires goals/standards be set by society and that appropriate management strategies be ecosystem based (EBM). Such management recognizes the holistic, inter-relatedness of ecosystems at various scales in space and time. It also recognises the interdependence among ecological, social, economic and institutional perspectives, considers cumulative effects, and applies the precautionary principle. A key goal of EBM is to sustain the ability of ecosystems to deliver all ecosystem services rather than the current preoccupation with the short-term provision of a single service (McLeod *et al*., 2005).

Of course, effective management needs the underpinning of scientific knowledge of the ecosystem in question, its linkages with adjacent ecosystems and its coupling with socio-economic systems. This need is magnified by the probability that climate change will have novel, unpredictable ecological effects (Schneider and Root, 1996) or cause abrupt, non-linear changes (Burkett *et al.,* 2005). Existing knowledge will thus be inadequate. In these circumstances, active adaptive management is highly recommended (Walters, 1986, Folke *et al*., 2002). Briefly, this is a learn-by-doing approach that views management policies and strategies as experiments elucidating the processes affecting EH. It requires adequate monitoring It also requires flexible social institutions that promote learning and can adapt when predictions are not met.

5. What Matters?

Questions are important if they contribute to meeting socio-cultural needs, which may vary geographically, and to the requirements mandated in legislation (eg, environmental protection, biodiversity conservation, state of environment (SoE) reporting, ecologically sustainable development, EIA). In all cases, basic research is necessary to underpin applied questions and explain applied research findings but they are not addressed here.

Of increasing importance are the pressures and their impacts associated with coastal squeeze. Managers with limited funds need to know which impacts matter (Jones 2003). What are the limits of acceptable change (Oliver, 1995)? What is meant by ‘detrimental’, ‘unacceptable change’, ‘significant impact’, ‘reasonable loss’, etc. (Fairweather and Cattell, 1990)? Under the Environment Protection and Biodiversity Conservation Act, the Australian Government (2009) defined a significant impact as an impact which is important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the environment which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts. Several criteria for significant impacts were erected. These include the establishment of pest species, habitat modification that will have an adverse impact on marine ecosystem functioning or integrity, and actions likely to have substantial adverse effects on populations of a marine species or cetacean including its life cycle and spatial distribution. However, from an ecocentric point of view, there is little scientific consensus concerning the *ecological* significance of impacts (Duinker and Beanlands, 1986). Instead, managers use value judgements (eg, the magnitude of change that is unacceptable) or non-biological standards (eg, water quality) to determine guidelines.

Despite this, it would be useful if pressures and their impacts could be prioritised according to severity or socio-economic significance. This ranking depends on the category of the pressure, the magnitude of biodiversity impacts, and recovery time. The following categories of pressure were suggested by Jones (2003) and Schlacher *et al.* (in press) as being of particular concern for the conservation of beaches and dunes (see also Dovers *et al.*, 1996 and Salafsky *et al.*, 2002):

- Pressures of large spatial scale eg, climate change. These pressures will affect all beaches.
- Pressures of large temporal scale i.e., persistent, press disturbances – (Bender et al., 1984) eg, climate change, coastal engineering and urban development. These will affect beaches for centuries
- Pressures that cause impacts to increase over time ie, ramp pressures (Lake, 2000) eg, the destruction of stabilizing plants on dunes exacerbates erosion.
- Interactive pressures that combine to produce larger effects than each pressure alone eg, the shell-weakening effects of acidification (Byrne, 2011, Chan *et al.*, 2012) may leave calcifying species more vulnerable to storm abrasion or crushing by vehicles.
- Boomerang disturbances (Webb, 1973) whose unforeseen effects rebound negatively on human interests e.g., building on dunes causes increased beach erosion.
- The cumulative effects of repeated activities, although individually small, eventually become unacceptable eg, progressive ribbon development along coasts.

In summary, the pressures covering large spatial and/or temporal scale are important, especially where habitat is changed or lost. In particular, climate change factors, especially warming, beach erosion and ocean acidification, are major pressures likely to affect beaches as are the effects of soft engineering (especially nourishment), hard engineering (especially seawalls) and off-road vehicles.

6. Questions

Most fields of scientific inquiry have areas of knowledge that are well known and others less so. For example, in sandy-beach ecology, there is substantial knowledge about the taxonomic composition and structure of macrofaunal assemblages, especially as they relate to different morphodynamic beach types or across-shore zonation (McLachlan and

Brown, 2006). As well, vegetated dune systems are considered to be vulnerable to disturbance than the beachface (Schlacher *et al*., in press). But less is known about functional processes that provide ecosystem services. These include microbial decomposition and re-mineralisation of nutrients (that support higher trophic levels including fish and birds) and photosynthesis (that provides carbon sequestration). Similarly, there is some knowledge about the ecological effects of nourishment (Speybroeck *et al*., 2006) but questions remain about the best engineering practice (discussed below).

The questions in Box 1 are listed under headings adapted from Schlacher *et al*. (2012) and workshops conducted at the Fifth International Symposium on Sandy Beaches held in Rabat, Morocco (2009). This listing is far from comprehensive. Rather; important questions were selected using the external criteria posited above and the existing state of knowledge. Following the listing, a few top priority areas of research, particularly nourishment, are nominated and discussed.

Box 1 – Selected important research questions relevant to the management of beaches and dunes on open-coast shorelines

Ecosystem services

- How much do intact beach ecosystems contribute to coastal economies?
- What critical ecological processes and structures cannot be compromised for these services to continue?
- How much do human activitites affect the range and value of ecological services provided by beaches and dunes?

Change & Impacts

- Are impacts likely to accumulate over time and how long will beaches take to recover from different forms of impact?
- What are the limits of 'acceptable change' for beach ecosystems?
- Can beach organisms adapt to altered seawater chemistry and erosion forces on coastlines caused by climate-change.

Conservation

- What are biologically effective yet realistic conservation goals for beaches and dunes of open-coast shorelines?
- What is the conservation status of beach species?
- What are the spatial design and implementation criteria for reserves on sandy coastlines (e.g. size, arrangement, biodiversity targets, societal expectations, etc.)?

Ecosystem management

- What are society's expecations and values about beaches and dunes that management needs to address in concert with ecological conservation?
- How can management measures maximise the ecological resilience of the dune-beach-nearshore system?
- Can coastal engineering (nourishment, seawalls) adopt ecologically more benign practices to reduce impacts?

Monitoring & Assessment

- Which suite of indicators offers the best combination of sensitivity, practicability, scientific robustness, and social acceptance to measure ecological changes on beaches?

7 Discussion

We have identified biological questions whose elucidation would enhance the management of sandy-beach ecosystems. This exercise was driven by the fact that sandy beaches are both threatened and vulnerable and there is relatively little biological research available to inform policy and management. This is especially true of Australia.

The importance/priority of questions depends on context. The following issues/questions are particularly important in the stated contexts. For example, in the context of ecological services and enhancing the public appreciation of beach biology (rather than just sand), quantifying functional microbial processes and their role in supporting larger, more-valued species is necessary. Secondly, in the context of management response strategies to ecologically-threatening processes, the role of nourishment in combating erosion will be a major issue. Indeed, nourishment is crucial to eroding urban beaches since the alternative response of building seawalls will lead to their disappearance (Pilkey and Wright, 1989). an unthinkable outcome for prized assets in coastal cities. Similarly, choices were made in the contexts of climate change, monitoring, conservation and the resilience of social-ecological systems.

7.1 Ecosystem services: functional processes

Beach management would be enhanced if there was greater public appreciation of beaches as living ecosystems providing services with human utlity, and greater acknowledgement by governments. For example, beaches are scarcely mentioned in government documents (Australian Government, 2009). This low profile is partly due to there being few flagship/charismatic beach species and the fact that beach biological research has largely neglected functional questions that elucidate ecological services, these being more easily grasped as being of anthropocentric utility. Moreover, "quantifying the value of these services and formulating the means for their management and continued provision in a changing world is a significant priority"and "there is a need to move from a description of ecological patterns to an understanding of the underlying ecological and socio-economic processes." (Nicholson *et al*., 2009, p. 1140). After all, human health, well-being and social stability all depend ultimately on maintenance of life-supporting ecological processes (Morton *et al.,* 2009).

A major service provided by sedimentary biota is the decomposition of organic matter and the re-mineralisation of nutrients by small benthic organisms, these nutrients being essential for photosynthetic organisms at the base of the food chain. In subtidal areas, much is known about these functional processes. They are strongly influenced by the sedimentary benthos that "contribute to regulation of carbon, nitrogen, and sulfur cycling, water column processes, pollutant distribution and fate, secondary production, and transport and stability of sediments" (Snelgrove *et al*.,1997, p.578).

In sandy-beach sediments, much less is known but there is evidence that benthic biota play a functional role in filtering seawater (Schlacher *et al*., 2008), decomposing organic matter (Coupland *et al*., 2007), recycling nutrients (Dugan *et al*., 2011). Consequently, the beach benthos can potentially contribute to the productivity of near-shore waters and the stocks of higher-profile species such as fish and shorebirds. But these processes have rarely been quantified in terms of nutrients or fish biomass let alone given a monetary value as done for global ecosystems by Costanza *et al*., (1997). What would be the consequences for fishing and bird populations if the functional processes operating within beach sediments were compromised by pressures and/or management strategies?

7.2 Change and impacts – climate change

Climate change will alter the sandy-beach habitat in several ways (Jones, 2011, Schlacher *et al*., in press). Of these, it seems likely that falling pH will be important, possibly in concert with other pressures, since calcifying species (eg, molluscs and crustaceans) dominate the biota and would be affected by acidification. But there appears to be no research addressing questions about the effects of, or possible adaptability or acclimation to increasing acidity on beach species?

7.3 Conservation

Conservation of biodiversity is a goal held at all levels of government. It is enhanced by the optimal siting of protected areas and this depends on knowledge of species' distributions and the locations of biogeographic provinces. Knowing the conservation status of keystone and endemic species is useful although the protection of entire ecosystems (including the beach habitat, its species, processes and people) rather than individual endangered species may well be more efficacious. Unfortunately, there is very little Australian knowledge of the biogeography of beach species and less about their conservation status.

7.4 Ecosystem management - nourishment

Of great importance are the effects of climate change with beaches being in the front line of sea-level rise, greater storminess and the consequent erosion. This is likely to result in more beach nourishment, increasingly the strategy of choice worldwide (Finkl and Walker, 2004). It was the choice of the Sydney Coastal Councils Group who commissioned a scoping study to "develop the outline of a sand nourishment programme utilising suitable offshore sand deposits for amenity enhancement and to ameliorate increased hazard risk from sea-level rise." (AECOM, 2010). The alternative strategy of coastal armouring using seawalls may protect built societal assets but would result in the total loss of the intertidal beach (Pilkey and Wright, 1989).

Although the ecological effects of nourishment has attracted worldwide research attention (Speybroeck *et al.*,2006), published Australian studies are limited to Jones *et al*. (2008) and Schlacher *et al*., (2012). As well, several questions concerning best engineering practice remain unexamined anywhere (Box 2). These include the location of fill placement, the depth of fill that may allow survival of buried resident biota, the spatial design incorporating unaffected beach areas to promote recovery, and the effects of repeated nourishment. In the SCCG scoping study mentioned above, suggestions for best practice (Box 2) were made by Jones (2010) on the basis of general ecological theory rather than specific empirical findings. As such, they should be tested scientifically and be subject to adaptive management.

Box 2. Nourishment Techniques: Questions and Best Practice for Ecological Outcomes. Adequate empirical information is available only for the first and last question.

Questions	Best Practice Recommendation Under Current Knowledge
Sediment grade	Use sediments that match the original beach sediments in terms of grain size and shell content.
Placement of fill	Placement in shallow subtidal may be best re both impact and recovery. Profile nourishment distributes sediment across the entire intertidal zone and may affect all species whereas foreshore and backshore nourishment has its greatest effects on the lower and upper beach.
Engineering techniques	Piping sediments from the borrow sites to the deposition sites as a slurry may enable some biota to survive.
Depth of deposition	Deposit the borrow sediments in shallow layers, thus enhancing the chances of survival by upwards burrowing.
Recovery islands	Intersperse some untouched areas among deposition areas to accelerate recovery. In particular, leave the southern part of the beach untouched to enhance recovery by longshore drift.
Timing	Time operations such that they conclude just before breeding seasons. Both the magnitude and duration of impact are affected by timing.
Altered beach profile	Retain original beach profile and morphology since beach biota are sensitive to beach morphodynamic state.

7.5 Monitoring

Monitoring is important in descriptive/status contexts (eg, temporal change and SoE) and human intervention contexts (eg, EIA and adaptive management). To test hypotheses about temporal change and/or the efficacy of the chosen management strategy, monitoring needs adequate design and robust statistical analyses. But there are no comprehensive recommendations for beach sampling protocols appropriate for different contexts. What sampling designs and response variables are optimal? Which are the quickest and cheapest short-cuts using easily-sampled surrogate species?

7.6 Resilience

Perhaps, ultimately, the most important questions involve resilience, both ecologically and in the holistic social-ecological system context (see eg, Walker and Salt 2006). What management strategies would enhance ecological resilience in the face of large, multiple environmental changes? How can ecological, social and economic components of the larger social-ecological system be integrated and optimized? Answering these questions poses great challenges and little practical progress has been made, but these challenges must be met to achieve ecologically sustainable development.

Finally, in relation to all the above issues, how can scientists be more effective in both their research and communication/advisory roles? Much ecological research to date has been good science with well-designed controlled experiments that test hypotheses. But these are are rare in intertidal beach ecology due to practical difficulties and, in any case, are usually restricted to small spatial scales of little relevance to management needs. As well, “good science, even when it is well packaged and accessible, does not guarantee good policy. The fact that policy questions are often ‘big’ and holistic in nature means that they are rarely tractable through individual research projects” (Pullin *et al.*, 2009, p.970). Other issues involve a temporal mismatch between funding cycles, the pressure to publish, and needs for long-term research concerning press disturbances or recovery periods (Lindenmayer *et al.*, 2012).

Concerning communication scientists would improve their effectiveness if they canvassed the needs of politicians, policy-makers, managers and business. Better and honest communication between policy-makers, managers, business and scientists could facilitate large-scale experiments that could well inform policy/management practice. Of course, such appeals to collaborate are not new. For example, “we urge ecologists to make better use of existing knowledge in dialogue with policy-makers and land managers. Because the challenges are enormous, ecologists will increasingly be engaging a wide range of other disciplines to help identify pathways towards a sustainable future.” Morton *et al.* (2009). Ultimately, effective research approaches by scientists may involve developing the kind of inter-disciplinary collaborative networks that address large-scale and long-term holistic questions about the resilience and sustainability of social-ecological systems.

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