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Sandy-beach ecosystems: Their health, resilience and management

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Lining most of the world's exposed shores, beach ecosystems are subject to numerous, increasing pressures imposed by burgeoning coastal development and climate change. Consequently, beach ecosystems are vulnerable and their ecological health and resilience are in question. This paper identifies the major threats to beaches, explores some of the ecological consequences, and discusses concepts of ecological health and resilience as applied to sandy shores. We also suggest some goals and strategies for coastal management and pose questions for which robust answers are currently lacking.

Major threats to beach ecosystems include climate-change factors, erosion, nourishment and/or hard engineering to combat erosion, off-road vehicles, beach cleaning, pollution, fisheries, sandmining and, possibly, introduced species. These factors may act singly or interact in novel ways. Probable consequences include changes to habitat structure and environmental conditions. In particular, climate change will increase the sea level, temperature and acidity and generate more intense storms causing greater habitat instability. In turn, these physico-chemical changes may affect the biological structure and function of beach assemblages. For example, temperature change would affect the distribution and physiology of many species and acidification would challenge calcifying species such as molluscs and crustaceans. Human responses to sea-level rise are also important eg, if hard engineering, especially seawalls, is used to protect societal assets, the adjacent intertidal beach will be lost entirely. Ultimately, sandy-shore systems may provide fewer ecosystem goods and services to society with severe social and economic consequences quite apart from the impairment of ecosystem health.

Although the term 'ecosystem health' (EH) is increasingly used in both a management and a scientific context, it is difficult to define precisely. Different definitions emphasise stability, sustainability, resilience, unimpeded trajectory to climax state, vitality, flourishing/good condition or similarity to pristine condition. Consequently, the concept of EH raises many questions. For example, if health refers to 'condition', does it mean optimum, natural, normal, productive, variable, stable or aesthetic condition? Does it mean a fit to a model (eg, Abundance Biomass Comparison) or the ability to resist or recover from disturbance, or any of these depending on context? It is also unclear whether an ecosystem in its natural state should necessarily be considered healthy given that natural variability can be large. How are alternative stable states interpreted in this context? Arguably, in practice, EH depends on what humans think ecosystems should be like according to a normative ideal. A pragmatic definition of EH is 'an ecosystem is healthy if it sustainably produces the outcomes desired by human society'. Some outcomes (eg, recreation, production) are driven by anthropocentric ethics, others (eg, conservation) by ecocentric ethics.

Of particular interest for beaches is the relationship between health and disturbance. A key premise is that beach biota are adapted to disturbance since they have experienced storms through evolutionary history. Secondly, disturbance may be necessary to maintain diversity/health (eg, intermediate disturbance hypothesis?). Moreover, disturbance type (ie, pulse, press or ramp) is important, particularly since some new threats (eg, increasing temperature and acidity) constitute press disturbances. Consequent questions arise. Will the biota adapt or acclimate to these press disturbances? Are there thresholds in frequency and intensity of storms that exceed tolerances? Will larger storms affect deep burrowers by reducing the depth of sand? Are biota adapted to new disturbances (eg, vehicles, beach cleaning and nourishment)? Will larger storms, vehicles and lower pH interact to affect biota? Will the effects of lower pH invalidate existing findings regarding vehicles? Will beach ecosystems recover after nourishment?

Some premises of EH are that ecosystems generally have not evolved into an optimum state, that natural ecosystems

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vary greatly (are all natural states equally healthy?), and that it is easier to recognise a lack of health (ecosystem distress) rather than the healthy state since no single optimum state exists. Ecosystem distress is characterised by a shift to smaller organisms, reduced species richness, loss of sensitive species, dominance by weedy and exotic species, shortened food chains, altered energy flows and nutrient cycling and likely reduced stability. However, apart from reduced species richness and abundance/biomass, these diagnostic tools have been little tested for beaches. Both large spatial scale diagnostics and comparisons over time (time series/ prior-post comparisons) are needed. Nor have alternative diagnostic approaches which are employed in other systems (e.g. ABC, River Invertebrate Prediction and Classification System) or biotic indices been developed for beaches, but there is some progress in testing the utility of indicator species such as ghost crabs.

Closely related to EH is resilience, a complex, ambiguous concept with two broad meanings. First, 'ecological resilience' has long been part of a semantically-confusing debate about ecological stability. In this ecological context, two main ideas are frequently presented: 1.) a system's ability to stay unchanged (resistance to stress/constancy/inertia), and 2.) the type and speed of change after impact (recovery/elasticity). The second meaning of resilience occurs where social and ecological systems (SESs) are integrated into 'holistic resilience'. This integration has arisen because of two false assumptions in natural resource policy. The first assumption is that ecosystem responses to human use are linear, predictable and controllable. The second is that human and natural systems can be treated independently. The increasing coastal population growth makes the latter assumption even less true for beach ecosystems.

Holistic resilience is both inclusive and complex. It is inclusive because it links economic, social and ecological systems and also accommodates panarchy, the cross-scale, dynamic interactions between human and natural systems. It is complex because it takes an holistic, dynamic systems view, considers spatial and temporal scales, and the synergisms of multiple pressures. Importantly, it recognises the possibility of non-linear, discontinuous ecological responses that create alternative states when thresholds have been exceeded. Although the SES approach is in its infancy, beaches may offer a particularly pertinent system for the application of SES-based management. Beaches are of immense social importance for recreation and coastal development (the social dimension of resilience) and they provide several critical ecosystem services dependent on intact ecosystems (the ecological dimension of resilience). Consequently, coastal managers should seek to reconcile ecological, social and economic demands in beach conservation, making holistic resilience an important management concept.

The purpose of management is to apply strategies that will achieve stated goals. For example, an overarching goal may be 'to sustain society (wellbeing and economy) and ecosystems (structure, function, processes, goods and services)'. For sandy shores, the goal might be 'to maintain beaches in a near-pristine state supporting fully diverse, functioning ecosystems and sustainable human uses'. The latter is consistent with ecologically sustainable development since a core objective is to protect biological diversity and maintain essential processes and life-support systems. Moreover, it is consistent with both ecocentric and anthropocentric ethics since the value of beaches to humans derives largely from their natural state.

Many key management questions for beaches arise. For example, will systems resist human-development and climate-change pressures, and if not, are the impacts in time and space acceptable? Will systems recover or adapt? Will systems slowly degrade or collapse to an unacceptable alternative state? What is unacceptable? These questions involve both scientific answers (eg, the first) and societal answers (eg, the last).

Although the available answers are rarely satisfactory, achieving societal goals will be served by enhancing resilience in terms of both ultimate (underlying) and proximate (direct) measures. The former include mitigating climate change, accepting limits to growth and the primacy of ecosystem protection, acknowledging beaches as ecosystems, increasing and disseminating knowledge, adopting human values/behaviours consistent with resilience, and applying ecosystem-based management principles (active adaptive management, the precautionary principle, risk analysis, cumulative effects, synergisms/multiple stresses, linkages and scale). Proximate measures include habitat/ environment maintenance, protecting dunes/sand budget, providing setbacks, applying best-practice engineering, minimising pollution, maintaining genetic diversity/population size, providing refuges as sources of colonists, and carefully managing potentially damaging activities (eg, mining, vehicles, camping etc).

As the World Resources Institute said in 2000 'The challenge for the 21st century, then, is to understand the vulnerabilities and resilience of ecosystems so that we can find ways to reconcile the demands of human development with the tolerances of nature.' This challenge applies to all ecosystems, not least beaches.