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Sandy beach conservation and recreation: Guidelines for optimising management strategies for multi-purpose use

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ABSTRACT

This paper addresses the need for a simple model for managers to employ when planning strategies for management of sandy beaches. It is based on the premise that in the overwhelming majority of cases beaches are suitable for recreation or for conservation or a combination of the two, whereas other uses are rare. The broad range of physical, ecological and socio-economic factors relevant to beaches, are reviewed briefly. Then three key factors are selected to develop each of two simple indices, an index of conservation value, CI, based on dune state of health, the presence of iconic species and macrobenthic species richness; and an index of recreation potential, RI, based on the extent of infrastructure, the level of safety/health of the beach and its physical carrying capacity. By combining these two indices, a beach can be simply classified as suitable for intensive recreation, or primarily for conservation, or for mixed use. Ten principles are outlined for consideration and potential application to beach management strategies. Finally, 23 beaches from three continents are classified, with detailed descriptions of a beach typical of each major use type.

1. Introduction

Human impacts on the world's shorelines are increasing due to expanding population, increasing affluence and increased demand for leisure on the coast, exacerbated by climate change and sea level rise (Defeo et al., 2009; Doney et al., 2012), not to mention extreme events (Jaramillo et al., 2012). The resultant 'coastal squeeze' and need for sound management of sandy beaches as valuable natural resources has never been greater. But many factors impinge on the coast and developing optimal strategies for beach management is not simple. Indeed, numerous indices, award systems and ratings have been developed for assessing beaches (Leatherman, 1997; Boevers, 2008; Cervantes and Espejel, 2008; reviewed in Williams and Micallef, 2009). The problem we perceive for assessing and managing beaches is dealing with multiple issues in a realistic way but without unnecessary complexity, and the need for basic tools to assist with this.

Factors impinging on beaches in ways that affect their use by humans include (Williams and Micallef, 2009): the geophysical environment and processes; the ecological and biological features and ecosystem processes; and socio-economic factors, including involvement of stakeholders. All these factors should be taken into account when managing beaches. Further, any management strategy needs not only to integrate these three suites of factors, but to be applicable across a wide range of spatial and temporal scales, and to be as objective as possible, preferably in a quantifiable way. Regional scale planning and management for multi-purpose use of beaches can consider three options for individual beaches at the local scale: management and use for recreation, management and use for conservation, management for multi-purpose use.

This paper attempts to provide a simple but relevant and robust framework for assessing beach condition and suitability for different uses from which guidelines for planning, management and monitoring can be derived. This is not a critical literature review; rather it attempts to distil down in a clear and straightforward manner the key features and processes relevant to planning for beach use and management. It is aimed primarily at coastal managers, but will also be relevant and of interest to scientists. We start by considering the broad suite of physical, ecological and socio-economic factors that could influence beach use and management. We develop from this multiplicity of forcing factors

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two simple indices, each based on three key measures: one to assess conservation value and the other recreation potential. We then proceed to outline key principles and guidelines for application of these indices and finally consider case studies to illustrate application.

2. Assessing the environment and conditions

The wide range of factors and issues that impinge on beaches as socio-ecological systems and affect their use and management can be grouped into 1) those relating to the physical environment, 2) ecological factors and 3) socio-economic issues. We outline briefly the main elements that contribute to each of these three categories. However, in most situations it will not be possible for mangers to consider all these elements in their entirety when deciding how to manage a beach. We will therefore, in the following section, proceed to select what we consider to be the key elements that need to be considered when identifying potential and priorities for two possibly conflicting uses of beaches, namely recreation and conservation.

2.1. Physical factors

2.1.1. Role of waves, sediment and tides

Beach systems consist of wave-deposited accumulations of sediment at the shore, complicated by the presence of tides, variable sediment and an ever varying wave climate, each of which will have a predictable impact on beach type and behaviour. Waves affect beaches in the shoaling, surf and swash zones, each having distinctive wave behaviour, wave–sediment interaction and resultant cross-shore gradient and morphology. Sediment deposited across the shoaling zone during high wave erosion events is slowly returned shoreward during beach recovery. The surf zone is the most dynamic part of the beach owing to the energy released by breaking waves, which can produce onshore (wave bores), longshore and offshore (rip currents) flows, and morphology containing single and multiple longshore and transverse bars, troughs and channels. The swash zone is where wave bores collapse on reaching the shoreline and run up the beach as laminar swash, partially percolate into the sediment and return as backwash, maintaining a relatively steep beach face slope. Sediment size and sorting will contribute to overall beach gradient and type, with fine sand maintaining a low gradient swash zone and a wide low gradient more dissipative surf zone. With increasing grain size the beach face will steepen and the surf zone narrow; coarse sand, cobble and boulder beaches having the steepest beach face and no surf zone. Tides are a component of most beaches and, with increasing vertical range, can have considerable impact on beach morphodynamics, as discussed in the following section. These three factors (sand, waves, tides) influence human use of beaches both individually and directly and also collectively through their determination of beach morphodynamic type.

2.1.2. Combining waves, tides and sand – morphodynamic models

Beaches can be classified into three broad types based on the relative tide range (RTR), which is the ratio of average breaker wave height (H_b) and spring tide range (TR) (Masselink and Short, 1993) where:

$$\mathrm{RTR} = TR/H_b \tag{1}$$

Beaches are wave-dominated when RTR <3, tide-dominated when RTR ≥10, and mixed or tide-modified between these types. These three broad beach types can then be subdivided into a range of beach states with the addition of the role of wave period (T, in seconds) and sediment size or fall velocity (W_s) using the dimensionless fall velocity (Ω) (Gourlay, 1968) where:

$$\Omega = H_b/T\,W_s \tag{2}$$

Wave-dominated beaches (Fig. 1) occur in areas of micro-tides (<2 m) where waves dominate the morphology with essentially stationary shoaling, surf and swash zones. At the lower energy end (H_b < 0.5 m) are steep reflective beaches often with coarse sand; with increasing wave height and/or finer sand are the rip-dominated intermediate beaches; then at higher energy (H_b > 2.5 m) occur low gradient fine sand dissipative beaches with wide multi-bar surf zones (Short, 1997, 1999). As tide range increases, these three zones are translated shoreward and seaward, and with each rise and fall of the tide resulting in a smearing of the three distinct processes and to some extent the three associated morphologies. Mixed or tide-modified beaches occur where tides increase to a few metres, resulting in a regular translation of the shoaling, surf and swash zone across a wide (100's m) sub- to intertidal area. There is a generally lower gradient and less well-defined surf zone topography. Typically they have a steeper reflective swash-dominated high tide beach, a wide and fairly featureless intertidal zone dominated by both surf and shoaling waves, and a low tide zone that may contain surf-generated bars and channels. Increasing tide range and/or very low waves (H_b << 0.5 m), results in tide-dominated beaches where the steep, coarser high tide beach is fronted by very wide (100's–1000's m) low gradient intertidal sand, which may be ridged, featureless or tidally arranged (Short, 2006).

2.1.3. Three-dimensional beaches and sediment transport

Beaches are naturally dynamic systems that respond continuously to changing wave–tide–wind conditions; they also become more complex in three dimensions, with horizontal and vertical wave-generated circulation, particularly in the surf and swash zones. During high wave events large erosion rip currents, together with bed return flow, rapidly (hours-days) transport sediment seaward into the shoaling wave zone, from where it can take weeks–months to return shoreward during lower waves. Sediment will also be transported longshore under oblique waves, which will induce a net alongshore flow of water and sediment in the areas of greatest wave-breaking. Longshore sediment transport is one of the

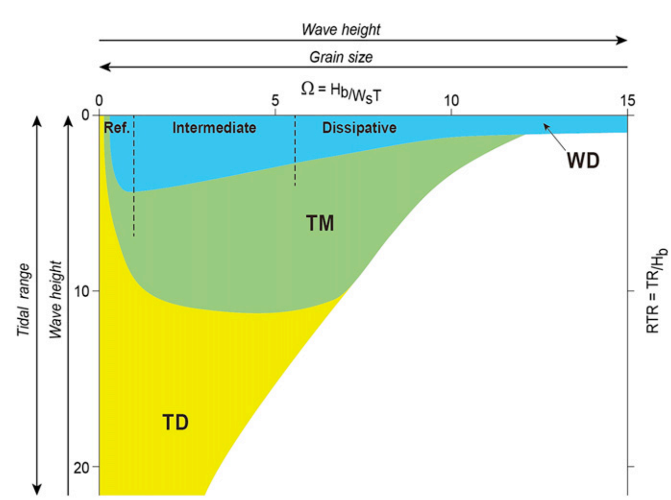

Fig. 1. Plot of dimensionless fall velocity (Ω) versus relative tide range (RTR) showing the general domain of reflective (ref), intermediate and dissipative beaches though the wave-dominated (WD), tide-modified (TM) and tide-dominated (TD) beach types (based on Scott et al., 2011; and Short and Jackson, in press).

greatest causes of shoreline change, with positive sediment budgets building beaches seaward, while negative budgets erode the beach and dunes to maintain sediment throughput. Longshore sand can be sourced from river/deltas, beach–dune erosion or offshore, while natural losses include longshore, inlets/estuaries, dunes and offshore (Clark, 1996).

2.1.4. Beach–dune interactions

Coastal dunes are sourced from the swash zone and as such are dependent for sediment on wave–beach–dune interactions (Short and Hesp, 1982), with the largest dune systems associated with high wave and wind energy coasts. Once initiated, coastal vegetation plays a critical role in dune stability and type. Dunes can be classified based on their stability/vegetation cover, with unstable partly vegetated dunes moving inland as transgressive dunes (blowouts, parabolic, long-walled parabolics and transverse dunes), whereas stable, well-vegetated regressive dunes can build seaward as successive foredune ridges.

2.1.5. Factors impacting beaches

The physical environment of beaches, and hence their suitability for conservation or recreation, is being impacted both by immediate human activities and by the longer term effects of climate change (Nordstrom, 2000; Defeo et al., 2009). Humans are having an increasingly adverse impact on many beach systems. Structures built seaward of or in or across the surf zone including breakwaters, river mouth training walls/jetties, groynes and reefs will modify wave–sediment processes (Charlier et al., 2005; Dugan et al., 2011). They will generally lower wave height and change wave direction at the shore and interrupt or stop longshore and/or shore normal sediment transport. Structures built on and at the back of the beach, particularly seawalls, will exacerbate beach erosion when exposed to waves, and prevent the backing dune store of sand from being utilized during erosion events. They also substantially degrade beach amenity and safety.

Human intervention may involve mining and removing sand from beach systems, thereby reducing the sediment budget, while other beaches are nourished, increasing the budget. Impacts also include regular beach grooming, construction on and degradation of coastal dunes and pollution of coastal waters. Furthermore, inland activities such as damming rivers, mining and deforestation can affect beaches via changes to river-borne sediment loads.

Human-induced climate change will have a range of impacts on beaches (Defeo et al., 2009; Doney et al., 2012). Rising sea level will result in approximately 50 m of beach retreat for every 1 m rise. Changing wave climates may induce more or less beach erosion, and more or less longshore sediment transport, whereas changing wind systems will impact coastal dunes and changing climate will influence the dune vegetation. Any change in tide range will also impact beach type and morphodynamics. Rising temperatures are already decreasing summer Arctic Ocean ice cover, resulting in longer higher energy open water periods, which will directly impact all Arctic Ocean beaches and those exposed to seasonal ice cover. In tropical–subtropical regions, rising water temperatures may lead to more and more intense tropical cyclones/hurricanes, which are already a major cause of beach erosion and coastal inundation.

2.2. Ecological factors

2.2.1. Dune vegetation

Abundant and diverse dune plant communities are a most sensitive measure of a healthy sand beach ecosystem, particularly as dune vegetation provides habitat to support a varied fauna, both terrestrial species and supralittoral species derived from the beach (Brown and McLachlan, 2002; Martínez and Psuty, 2004). Naturally stabilized dunes provide a range of habitats that are not constrained by erosion or impacted by coastal development (Feagin et al., 2005a). Where undisturbed, dunes may be open transgressive sand in regions of high sand transport and/or low rainfall, or highly vegetated and stable in humid regions (Hesp, 1991). Vegetation zones range from low pioneers closest to the beach to secondary shrubs then climax inland, the type and level of the climax depending on rainfall (Feagin et al., 2005b). Dunes and their vegetation may be disturbed in many ways: in some areas exotic species have been introduced to stabilize dunes and therefore impact the dune ecosystem; pedestrian and vehicle access results in trampling that damages vegetation; and development may encroach on, flatten or remove dunes. All of these compromise the viability of the dune ecosystem (e.g. Martinez and Psuty, 2004).

2.2.2. Endangered and iconic species

Sandy beaches serve as breeding habitat for diverse vertebrates and some charismatic invertebrates (McLachlan and Brown, 2006). For example horseshoe crabs (*Limulus polyphemus*) use Atlantic and Gulf of Mexico beaches to breed (Rudloe, 1980; Tanacredi et al., 2009; Brockman and Johnson, 2011) and grunion fishes *Leuresthes tenuis* spawn on sandy beaches located between Point Conception in southern California and Punta Abreojos in Baja California, Mexico (Moffatt and Thomson, 1975; Griem and Martin, 2000). Sea turtles also come ashore throughout the tropics to bury their eggs in sandy beaches and foredunes above the high tide during their breeding season (Reynolds et al., 1977; Griem and Martin, 2000). Several species of shorebirds use sparsely vegetated ocean sandy beaches and foredunes as breeding grounds (Colwell et al., 2005; McLachlan and Brown, 2006). Though not threatened globally, most populations are of conservation concern due to the fact that these nesting grounds are increasingly being threatened by coastal development.

Increasing coastal development stands as a significant threat to the above mentioned organisms. Artificial armouring by seawalls and revetments as well as grooming using bulldozers and large rakes can diminish or even eliminate spawning grounds of horseshoe crabs, grunion fishes and sea turtles (Rizkalla and Savage, 2011; Veloso et al., 2008). Even pedestrian and vehicle traffic can have huge impacts and disturbances (van der Merwe, 1988; Rickard et al., 1994). For these reasons, and due to a general public awareness of the increasing need to protect these organisms, we consider them as iconic sandy beach species. Consequently, their presence and conservation status must be taken into account when assessment of management strategies for multiple-purpose usages of beaches is undertaken.

2.2.3. Macrobenthic diversity and abundance

Dissipative and reflective beaches are located at opposite ends of the beach morphodynamic spectrum and differ greatly in macrofaunal communities. Dissipative beaches with gentle slopes and fine sand provide less hostile conditions to the intertidal macrofauna than do reflective beaches; consequently, dissipative conditions result in higher species richness, population abundances and biomass of macrobenthic fauna than reflective beaches (Fig. 2; Brown and McLachlan, 2002). This has been demonstrated in close relationships between species richness, abundance and biomass of the intertidal macrofauna and beach features (including the dimensionless fall velocity, equation (2)), which has become a current paradigm in beach ecology (see e.g. McLachlan et al., 1993, 2005; McLachlan and Defeo, 2013). Furthermore, some dissipative beaches harbour huge populations of edible invertebrates, especially clams, enabling the development of recreational or artisanal fisheries (McLachlan et al., 1996; Defeo, 2003). Besides exploitation

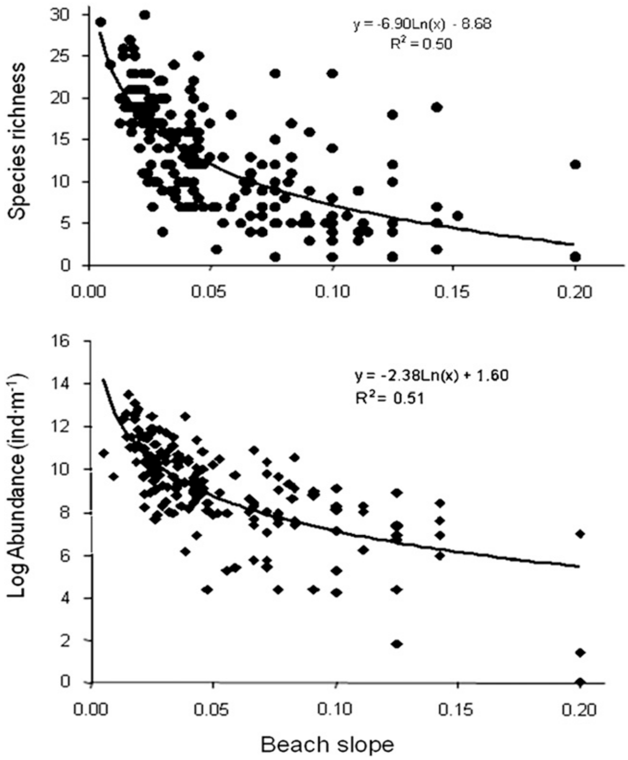

Fig. 2. Relationship between macrobenthic species richness and abundance and beach type as measured by beach slope. Flatter and wider beaches (i.e. more dissipative and with larger tide ranges) support richer faunas (after McLachlan and Defeo, 2013).

of invertebrate populations, human impacts on beach macrofauna can include physical damage due to trampling and vehicles, especially where abundances are high (Schlacher et al., 2008).

2.2.4. Ecosystem processes

Beaches are marine systems that exchange materials with the sea, in the water column and through groundwater seepage, and to a lesser extent with foredunes. In addition, a variety of supralittoral and terrestrial fauna can move across the dune/beach interface. Important ecosystem processes on sandy beaches include the filtration of seawater and mineralization of its organic materials by the interstitial fauna in beach sand; the nursery role of surf zones for inshore fishes; and the initiation of rich food chains where surf zone diatoms are abundant (McLachlan and Brown, 2006). Wrack deposits provide significant sources of food and microhabitat refuge against desiccation for supralittoral fauna consisting of crustaceans and insects (e.g. McLachlan, 1985; Dugan et al., 2003; Colombini and Chelazzi, 2003). However, on beaches with high recreational potential, biodiversity conservation is less important, and ecologically damaging beach cleaning or grooming to remove wrack may be a common practice (Dugan et al., 2003; Davenport and Davenport, 2006). These ecosystem processes and human interventions both influence recreation patterns on beaches and provide important considerations for beach conservation.

2.3. Socio-economic factors

The potential uses of a beach from a socio-economic point of view are based on several factors: 1) available infrastructure to support recreation activity, 2) the safety and health status of the beach environment, 3) the physical carrying capacity or extent of the beach, 4) commercial use of the beach for extraction of living or non-living resources, and 5) the local socio-economic environment.

2.3.1. Infrastructure

A critical point for the categorization of beaches based on socio-economic factors is infrastructure, which is essential for intensive recreation. Following the classification provided by Micallef and Williams (2004), beaches with good infrastructure represent areas where recreational use value far exceeds that of biodiversity conservation and/or management of valuable resources. Good infrastructure would include road access, ample parking and free and safe entry to the beach, facilities such as toilets and showers, plus kiosks etc, and lifesaving support. Hotels, restaurants, and related recreational amenities may also be required to maximise amenities in high use areas.

2.3.2. Safety and health

Beach safety and health are sensitive socio-economic issues for assessing sandy beach condition because of the immense value of beaches for recreation and tourism. Safety primarily concerns bather safety in terms of dangerous rip currents and beach exposure to waves, whereas health relates to absence of pollutants or any source of infection. Beach safety includes several related parameters (e.g. lifeguards, beach and sea state; see Micallef and Williams, 2004) and can be assessed using Short's (1999) hazard rating scale. Beach safety is best on low energy reflective and low tide terrace beaches, with hazards increasing with increasing wave exposure and coarser sands (steeper beaches). Hazards can be mitigated with the provision of appropriate beach safety resources, especially lifeguards.

Management of beach health requires continuous monitoring of water and sediment quality (Pereira et al., 2003). Pollutants include a variety of anthropogenic materials acting at several spatio-temporal scales, causing aesthetic disturbances that impact those tourism industries that depend on public perceptions of clean beaches (Tudor and Williams, 2003). Some may not be visible or have aesthetic impacts and may impact beach health without causing any obvious disturbances. Beach classification systems developed for the assessment and monitoring of recreational water quality (WHO, 1999) explicitly include health risks through a combination of microbiological indicators of faecal contamination and an inspection-based-assessment of sustainability of the bathing area (Defeo et al., 2009). Economic losses can arise on tourist beaches persistently contaminated by litter, wastewater, sewage, and even wrack (reviewed in Defeo et al., 2009).

Beach type and exposure influence the intensity and persistence of pollutants. Low energy sheltered beaches, even with fine sediment, are generally more sensitive to pollution than exposed beaches, because they are less well flushed by wave action and contaminants persist longer than in exposed beaches (Sindermann, 1996). Likewise, the coarser the sediment (i.e., reflective beaches), the more rapidly and deeply pollutants (e.g. oil) penetrate, potentially reaching below the groundwater table and causing greatest pollution (Bernabeu et al., 2006).

2.3.3. Physical carrying capacity

Physical carrying capacity relates to the length and width of the beach and especially the extent of the subaerial beach above the high water mark, a zone which is available for beach-users at all times. To carry large numbers of users, a beach must have good access, length and width and adequate space between the wet shore and the dunes/amenities. Many popular beaches have been extended landward by trampling or removing the foredune system. This can to some extent be influenced or managed by controlling parking and pedestrian access.

2.3.4. Local economy and commercial uses for living and non-living resources

Harvesting of intertidal sandy beach macrofauna and surf zone fishes is the commonest form of exploitation on sandy beaches (McLachlan et al., 1996). However, resource targeting in sandy beaches tends to involve a complex blend of users, requiring the explicit incorporation of cultural, social and political dimensions in resource management (Castilla and Defeo, 2001). Indeed, three different kinds of exploitation patterns and stakeholders usually occur in sandy beach fisheries: a) recreational users; b) subsistence gatherers; and c) commercial fisheries. In addition, multiple use beaches that simultaneously involve resource exploitation, recreation and conservation issues are being increasingly documented worldwide (see Table 3 number 4, Barra del Chuy). Non-living resources are also exploited from sandy beaches: beach sands are frequently mined and used for building, and excavated for the extraction of diamonds and heavy minerals such as titanium and zirconium (Clark, 1996; McLachlan et al., 1996; Ghosh et al., 2006). Sand removal alters the sediment budget and hastens erosion, affecting the morphodynamic state of beaches (Thornton et al., 2006). Most of these activities negatively impact dune ecosystems (including nesting sites for shorebirds and turtles) and also the diversity and abundance of intertidal benthic communities (reviewed in Defeo et al., 2009). Finally, the socio-economic status of the surrounding region and the nature and extent of tourism also impact beach use patterns.

3. Comparing conservation value against recreation potential

The two primary uses of ocean beaches are for conservation and recreation. The following is based on the principle that, to some extent, these two options are mutually exclusive, i.e. intensive recreation and effective conservation, cannot be practised simultaneously on the same section of beach, although intermediate conditions could occur. We then proceed to identify the three key drivers in each case and use these to assess how important or useable a beach is for conservation or recreation. Based on this, we develop a simple scoring system for evaluating the potential/suitability of a beach for conservation and/or recreation.

3.1. Conservation value

The conservation value of a beach is here considered to be determined primarily by three factors, in order of decreasing importance: 1) the extent, nature and condition of the dunes and their vegetation, and their connection with the beach; 2) whether any rare or endangered and iconic species that are particularly susceptible to disturbance are present; and 3) the abundance and diversity of the intertidal benthic macrofauna. For dunes, the highest conservation value is placed on systems that are intact, undisturbed, with well-developed indigenous vegetation displaying clear shore normal zones, and also unhindered dune–beach coupling and sand exchange. Dunes replaced by hard engineering structures or severely disturbed, with invading exotic species and impediments to dune–beach sand exchange, would represent the lowest conservation value. Endangered and iconic species are typically breeding shorebird colonies and nesting turtles, but may include seals, horseshoe crabs and grunion. Macrobenthic community abundance and species richness are directly coupled to beach type (McLachlan and Dorvlo, 2005) and are richest in macrotidal dissipative situations and poorest in reflective situations. The scoring system in Table 1 is based on these three measures and results in *Conservation Index* (CI) scores from 0 to 10 in an increasing level of conservation value.

3.2. Recreation potential

The recreation value or potential of a beach can be assessed on the basis of three factors: available infrastructure to support recreation activity, the safety and health status of the beach environment, and the physical carrying capacity or extent of the beach (Table 2). Good infrastructure would include road access, ample parking and safe entry to the beach, facilities such as toilets and showers, plus kiosks etc., and lifesaving support. Safety primarily concerns bather safety in terms of hazardous surf conditions and beach exposure to large waves, risks which can be mitigated by the provision of beach safety resources (lifeguards, rescue equipment, etc.). Health relates to absence of pollutants or any source of infection. Physical carrying capacity relates to the length and width of the beach and especially the extent of the subaerial beach above the high water mark, a zone that is useable at all times. For intensive recreation, good infrastructure is essential. Safety can be assessed using Short's (1999) hazard rating scale, which ranges from a score of 1 for least hazardous to 10 for extremely hazardous with great wave exposure and coarser sands (steeper beaches). To carry large numbers of recreationists, a beach must have significant shoreline length and width and adequate space between the wet shore and the dunes/amenities. Adding individual scores for these three parameters results in *Recreation Index* (RI) scores from 0 to 10, in order of increasing recreation potential (Table 2).

3.3. Combining conservation and recreation indices

The indices summarised in Tables 1 and 2 can be combined and used jointly to compare beaches and identify which areas (or sections of beach) should be demarcated for conservation, which for recreation and which for multi-purpose use. When the CI scores for conservation and the RI scores for recreation are plotted against

Table 1
Index of conservation value (CI).

Category	Condition and score					
Dunes	**0** Absent, replaced by hard engineering structures	**1** Severely disturbed and limited in extent	**2** Extensive disturbance	**3** Disturbed but largely intact	**4** Well developed, little disturbance	**5** Pristine and extensive
Endangered and iconic species	**0** Absent	**1** Present in low numbers, not nesting	**2** Present in good numbers, may be nesting	**3** Nesting/spawning present in large numbers		
Macrobenthic diversity and abundance	**0** Low abundance, reflective and/or short beach	**1** Intermediate	**2** Species rich and abundant, dissipative and/or long beach			
Total score	**Minimum score is 0 + 0 + 0 = 0; maximum score is 5 + 3 + 2 = 10**					

Table 2
Index of recreation potential (RI).

Category	Condition and score					
Infrastructure	**0** No infrastructure, difficult access	**1** No infrastructure, limited access	**2** Modest infrastructure reasonable access	**3** Good access, some amenities	**4** Good infrastructure and access	**5** Excellent access, parking and amenities, including lifesaving
Safety and health	**0** Extremely hazardous and/or polluted	**1** Hazardous and/or polluted	**2** Moderate hazards and clean	**3** Low bathing hazards, clean and totally pollution free		
Physical carrying capacity	**0** Limited, pocket beach, no backshore	**1** Intermediate	**2** Extensive beach with wide backshore			
Total score	**Minimum score is 0** plus; **0** + **0** = **0**; **maximum score is 5** + **3** + **2** = **10**					

each other the model illustrated in Fig. 3 provides a conceptual basis for management strategies.

Beaches scoring above 5 for CI and below 5 for RI (zone A in Fig. 3) should be managed primarily for conservation, with limited recreation and no exploitation activities, whereas beaches scoring above 5 for RI and below 5 for CI (zone B in Fig. 3) should be managed for intensive recreation. A key feature of either form of management is through access control: restricting access (spatially and/or temporally) to beaches requiring conservation but providing good access for recreational beaches. Between these two extremes, beaches in zone C can be managed for multi-purpose use, with those above the centre diagonal line biased towards recreation and those below the line towards conservation. Beaches scoring low on both indices (zone D), will have very limited use and minimal management will be necessary. Beaches scoring >7 on both indices (zone E), will have high potential for recreation and equally high value for conservation and will therefore need to be managed carefully, most likely separating conflicting uses spatially and/or temporally. Use of beaches for purposes other than conservation and recreation may include fisheries and extraction of sand. While the former may overlap with recreation in some cases, the latter is

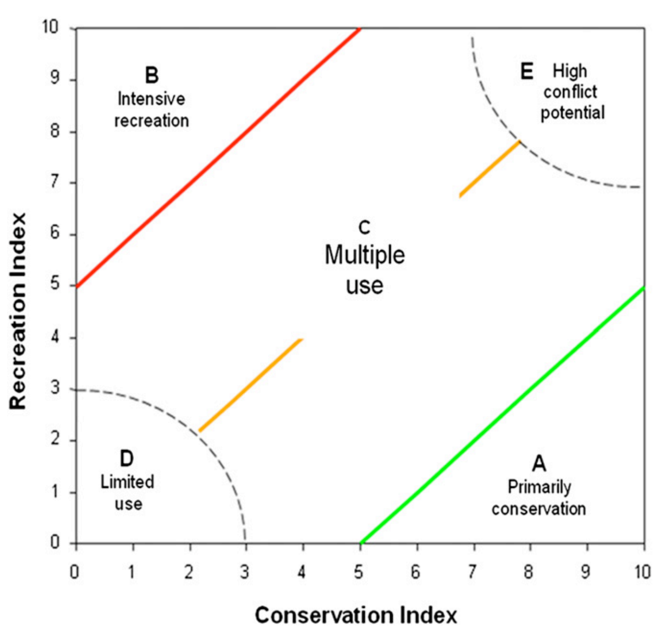

Fig. 3. Plot of Recreation Index against Conservation Index scores to show demarcation of beaches for intensive recreation, conservation and multi-purpose use. See text for explanation.

usually purely commercial, but these are limited cases that should be considered outside the above models.

4. Underlying principles

We recommend the following ten key principles to be borne in mind when working from the two indices to implement management strategies. Their relevance and relative importance will vary in different situations but, ideally, the coastal manager should be able to address all of these principles, even if only to a modest extent.

4.1. Identify the basic physical processes and scales relevant to a beach

It is essential to characterise a beach in terms of its morphodynamic type and the associated broad physical processes and features: wave-dominated, tide-dominated or mixed (tide-modified); then within each type beaches can range from the lower energy reflective to higher energy dissipative. Further, local factors, such as headlands, will influence beach length and orientation and the degree of longshore sand transport; this is especially important on relatively short beaches where the length of beach between headlands is less than 2 km. Since beaches and dunes are coupled by sand exchange and storage, dune extent, vegetation cover and type must also be taken into account. These characteristics will all impact on the ecology, safety, sensitivities and other features listed below and will therefore determine what uses and strategies are best suited for a beach.

4.2. Recognise the basic ecological features of beaches and dunes

Beach ecology is a function of its bio-geographic location coupled with beach type. Long and wide dissipative beaches will harbour a higher diversity and abundance of macro-invertebrates than shorter and narrower reflective beaches; and tropical beaches tend to support higher diversity but lower abundance than temperate beaches of the same morphodynamic type. However, where dissipative beaches harbour large invertebrate populations, they may be susceptible to disturbance or exploitation as recreational or traditional fisheries, requiring management strategies. Likewise, dune type and vegetation structure and zonation are best developed on wide, stable humid dune systems, with up to four zones recognisable – primary (pioneer grasses, succulents and creepers), secondary (shrubs), tertiary (thicket, woodland) and climax (forest) (Tinley, 1985). Foredunes and their vegetation are the most sensitive part of the system to human disturbance, with the unvegetated beach systems generally more robust. Where beaches have no dune backing, such as where there is a cliff or engineering structure directly against the backshore, the beach will tend to disappear during erosional events and will therefore have limited conservation value.

4.3. Identify shoreline status and whether erosion needs to be addressed

All beaches are naturally dynamic, some experiencing long-term erosion, while others are stable and a few are even prograding seaward. It is therefore critical to determine the long-term trend in past shoreline position (eroding, stable or accreting) using profile surveys or aerial photographs, and to superimpose on this the possible future the impacts of climate change. These trends can then be used, where possible, to determine the extent of *setback zones* (Clark, 1996) required to protect present and future development from shoreline retreat by providing additional space between infrastructure-development and the impacts of beach erosion and even storm surge and tsunami. The greater and more imminent the threat the greater the setback required. With the threat of climate change, most setbacks will now include a factor to accommodate rising sea level. If there is significant erosion and shoreline retreat, it is desirable to weigh how best to cater for this by deploying one of the following options in order of decreasing preference from the ecological point of view: do nothing, managed retreat, nourishment, armouring.

4.4. Recognise any significant anthropogenic disturbances

Stabilization of the dynamic shoreline though construction of groynes and seawalls to prevent beach erosion or longshore transport represents a permanent disturbance and may degrade the beach as well as beach amenity. These structures also increase public risk and in some case even exacerbate erosion (Dugan et al., 2008, 2011). Each beach has a 'storm demand', the amount of sand removed during storm events, which must be available to be eroded offshore and then later returned shorewards for beach recovery. If this demand is compromised by sand removal or alienated by seawalls, then the sand must be sourced from elsewhere, also causing erosion. On a finer scale, grooming by using bulldozers and large rakes, damages the spawning and nesting grounds of iconic species and could affect key species exploited by artisanal communities. Finally, pollution can be a local problem. To address these issues it is necessary to assess the frequency and magnitude of press and pulse disturbances, catalogue the likely impacts, provide long-term projections of different scenarios of magnitude, frequency and intensity, and identify early warnings of tipping points.

4.5. Protect the foredunes as a buffer

Pristine intermediate and dissipative sand beaches often have well-developed dune systems with successional vegetation stages, which provide refuge for supralittoral fauna and breeding grounds for coastal birds. Even microtidal reflective beaches, when undisturbed, are backed by a foredune ridge. This vegetation is particularly sensitive to disturbance. Irrespective of the need for or presence of setback zones, there should, ideally, always be a foredune zone to act as a natural buffer between waves, swash, storm surge, wind, aerosols and wind-blown sand and any backing infrastructure. In its simplest form this should incorporate the vegetated foredune, which can act as an effective buffer to most the above, though storm surge and tsunami may overrun a foredune. The dune buffer zone also maintains the beach integrity and amenity by offering a natural view-scape behind the beach and possibly masking backing infrastructure. The buffer and setback (see Section 3 above) also provide space to accommodate landward migration of beach–dune ecosystems during the coastal squeeze resulting from sea level rise.

4.6. Use alongshore zoning for multiple use planning

Different sections of shoreline may be most suitable for conservation, recreation and other uses, such as resource management. Coastal zoning, accommodating human demands for coastal access and development while recognising the need to preserve representative coastal environments, is a trade off between the growing pressure to develop and the increasing need to conserve, particularly with the threat of coastal squeeze as sea levels rise. Zoning, the best strategy for planning and management multiple beach uses, requires identifying natural alongshore demarcations/boundaries and placing buffer zones between intensive use and conservation areas. Zoning can also be temporal, i.e. sections of beach may have certain uses precluded during certain seasons, such as breeding seasons for shorebirds. Controlling access is an essential tool for implementing zoning of uses (see Section 7 below). Ideally, conservation zones should include a representative suite of coastal-beach environments and the adjacent water bodies. In already developed coastal areas the zones may be disjointed, with conservation nodes surrounded by developed terrain. It also needs to be borne in mind that for conservation to be effective, a minimum beach area/length is required.

4.7. Control access

A key tool to manage use of beaches is by controlling access in order to (i) control use levels or numbers of users, (ii) focus use on specific sections of beach, and (iii) protect sensitive dune habitats and iconic species. This includes location of access roads, size of car parks, walkways through dunes etc. It is necessary to control (i) the numbers of beach-users (low numbers for conservation beaches, high numbers for recreation beaches), (ii) nature of use (swimming, surfing, fishing, harvesting, etc.) and (iii) the means of access (ranging from direct access to the beach from car park, through intermediate levels, to extended raised boardwalks over dunes to protect vegetation) to fit the intended use pattern, carrying capacity and strategy. Only in exceptional cases should off-road vehicles (ORVs) be allowed on beaches as they are not compatible with conservation and impair the recreation experience of non-vehicle users. Access may need to extend through buffer and setback zones where they exist; ideally this should be as raised walkways if it passes though the dune buffer zone.

4.8. Health and safety

Beaches are favoured sites for summer recreation and in popular locations need to accommodate large numbers of people safely and healthily, so a number of factors need to be considered. In terms of beach safety, the less hazardous lower energy wave-dominated and tide-modified beaches will be preferred, with tide-dominated beaches offering wide tidal flats and consequently little in terms of beach recreation at mid to low tide. All beaches present some hazards to the public, including deep water, breaking waves, rip currents and variable water depth, as well as biological hazards such as sharks and stingers. The level of physical beach hazard is a function of beach type and prevailing wave–tide conditions (Short, 1999), and can be partly mitigated with the application of appropriate beach safety resources (lifeguards, signage, education, equipment, etc.). Beach contamination, especially though water pollution, should be addressed at the pollution source, which may be some distance away, but local monitoring is essential in areas of intense recreation (Tseng and Jiamg, 2012). The public can be informed of water quality levels and the beach temporarily closed when the quality deteriorates. Beach cleanliness can be addressed on site with beach raking and grooming, as well as provision of litter containers.

4.9. Managing exploited resources: sandy beaches as socio-ecological systems

Some beaches have large exploitable populations, usually of clams (McLachlan et al., 1996). In such cases it is necessary to provide robust and efficacious long-term management interventions based on a comprehensive understanding of beaches as social-ecological systems. Such complex adaptive systems must include biophysical (ecological and geomorphological) and human (cultural, economic, political, and ethical aspects) subsystems that operate through interdependent feedback relationships. Fragmenting this comprehensive framework or considering only one subsystem will give a distorted view that will lead to unsustainable exploitation of resources. Co-management by cooperation between the managers and the community is generally necessary for effective implementation (Gutiérrez et al., 2011), but it must be recognised that episodic events, like mass mortalities driven by climate variability, may swamp management schemes (Defeo, 2003).

4.10. Governance: policy, planning and implementation

The effectiveness of beach management is in no small way related to the capabilities of local authorities. A combination of weak governance, globalization of markets, fishing pressure and climate change has exacerbated unsustainable practices in the case of many sandy beaches. Sandy beaches as social-ecological entities require the implementation of resilient yet adaptive management systems and effective governance under pressing conditions of change and uncertainty. Cooperation among stakeholders is essential (Tabet and Fanning, 2012). Spatial property rights, well-defined rules and participation of key stakeholders during the management process (co-management) can result in successful local practices for governing these ecosystems. But all this is ineffective without rigorous implementation.

5. Case studies

Table 3 provides a concise summary, drawn from three continents, of 23 cases of beach usage to illustrate the application of these two indices. Each beach is scored on all six parameters and rated for both conservation value (CI) and recreation potential (RI). The ensuing management strategy is also indicated in Table 3 and the position of each beach in terms of CI and RI scores is illustrated in Fig. 4.

These 23 cases can be simplified to five main categories as illustrated in Figs. 3 and 4. We therefore expand as follows on five of the cases listed in Table 3 to illustrate in more detail the main scenarios in order to provide further insight and illustrate the approach adopted:

Example 1. Sundays River Beach, South Africa (Table 3 number 2)

Theme/Strategy: Conservation

Relevant principles/guidelines: 1, 2, 3, 4, 7, 10

Description: This is a 40 km long wilderness beach backed by an extensive transgressive dune sheet which is 2 km wide and rises to nearly 200 m. The beach, nearshore and dunes all lie in the Greater Addo National Park, which also extends offshore to include nearby islands (as a marine park). The climate is warm temperate and rainfall averages 600 mm p.a. Access is on foot and only at Sundays River mouth at the western end, and from a farm 20 km further east, behind the dunefield. Off-road vehicles (ORVs) are not allowed. The dunefield is slowly accreting and advancing inland and has varied indigenous vegetation, climaxing in forest along its landward edge. Wildlife is diverse and abundant. The beach is of the high energy intermediate type, micro/mesotidal, with moderately rich and productive macrofauna. Two seabird species, Damara terns and African black oyster-catchers, breed along the beach/dune margin. Human activity is very limited, some fishermen using the first few kilometres of beach near the river mouth, and occasional walkers visiting the area. The area is protected and managed by the National Parks service and no other strategy is needed, except for dealing with invasive exotic vegetation in a small section at the western end of the dunefield.

Example 2. Barra del Chuy, Uruguay (Table 3 number 4)

Theme/strategy: Mixed use

Relevant principles/guidelines: 1, 2, 4, 5, 6, 7, 9, 10

Description: This is a 22 km exposed dissipative beach characterized by its gentle slope, fine sands, persistent wave action, wide surf zone and a micro-tide range (0.5 m), and supports the highest richness, diversity, abundance and biomass of macrofauna among Uruguayan beaches (Lercari and Defeo, 2006). In the south the Andreoni Canal discharges freshwater, generating a strong alongshore salinity gradient and erosion of the beach (Defeo and de Alava, 1995). Before 1990 the main stressors were open access to the yellow clam (*Mesodesma mactroides*) fishery and the freshwater discharge by the Canal (Castilla and Defeo, 2001). Several ecosystem services were degraded or used unsustainably, including fisheries, regulation of water quality and erosion, and aesthetic enjoyment (tourism). Several bird species, some of them endangered, directly use the sandy beach as breeding grounds, increasing its conservation value. In 1987, coastal marine authorities, scientists and local fishers agreed on the implementation of a 2-year fishery closure (Defeo, 1996) following which adult clam density increased by more than 400%, resulting in the fishery being reopened in 1989 with management strategies (Castilla and Defeo, 2001) that included i) a monthly total allowable catch; ii) a restricted number of fishing licenses; iii) an individual quota per fisher; and iv) a spatial management scheme. This zoning strategy included the allocation of co-ownership authority to groups of fishers in beach management units with well-defined boundaries. This spatial marine planning approach also included additional measures to allow for multiple uses, such as the restriction of fishing activities during summer in zones close to the resorts of La Coronilla and Barra del Chuy (temporal zoning). Some initiatives were taken to regulate the magnitude of the canal discharge to the beach and preserve the well-developed sand dunes. Today, this beach constitutes a multiple use system, with closure to harvesting of selected portions of the beach, which are mainly utilized by tourists. In addition, efforts to mitigate the influence of freshwater discharge to the beach have succeeded, allowing the recovery of marine conditions in the coastal zone, a moderate recuperation of beach quality and an increase in tourism activities. Finally, changes in governance from a top-down system to a co-managed arrangement provided impetus for monitoring, control and surveillance by the fishers themselves, lowering costs for government agencies and empowering the fishers.

Example 3. Mon Repos, Queensland, Australia (Table 3 number 11)

Theme/strategy: Mixed use, high conservation and recreation values, high conflict potential

Relevant principles/guidelines: 2, 5, 6, 7, 10

Table 3
Summary of 23 cases of beach ratings using CI and RI and listing the management strategies applied.

Beach name and location	Dune status	Iconic species	Macro-benthos	CI	Infrastructure	Safety health	Carrying capacity	RI	Strategy applied
1. King's Beach, Port Elizabeth, South Africa 33°57′S 25°39′E	2 Mainly artificial dunes, vegetated	0 None	0 Sparse	2	4 Good facilities, including lifesaving	3 Clean and safe for bathing	2 Wide backshore because accreting	9	Recreation: Accreting urban beach, ideal for recreation, no conservation issues
2. Sunday's River Beach, Port Elizabeth, South Africa 33°43′S 25°53′E	5 Extensive transgressive dune system	2 Damara terns and oyster-catchers breeding in low numbers	1 Modest clam population, not exploited	8	0 None, difficult access	1 Exposed and dangerous	2 Extensive beach and dune system	3	Conservation: Wilderness beach in a national park, limited recreation, no ORVs
3. Maitland River Beach, Port Elizabeth, South Africa 33°59′S 25°16′E	4 Large transgressive dunes, some disturbance	1 Oyster-catchers may be nesting	2 Rich fauna, large clam population, exploited in recreational fishery	7	2 Fairly good access and parking, limited facilities	0 Exposed and dangerous	2 Extensive, used mainly for fishing	4	Mixed use: Recreation – clam collecting, fishing, walking, limited swimming; some management of harvesting needed; ORVs not allowed
4. Barra del Chuy, Uruguay 33°49′S 53°27′W	4 Large transgressive dunes, some disturbance	2 Oyster-catchers nesting, unique clam population in the country	2 Rich fauna, large clam population, exploited in recreational fishery	8	3 Some facilities, including lifesaving in allowed sites	2 Clean and safe for bathing only in allowed sites	2 Extensive, used for fishing and recreation. Extensive dune system	7	Mixed use: Recreation – clam collecting, fishing, walking, limited swimming; management of harvesting in place; ORVs not allowed
5. Punta del Diablo, Uruguay 34°04′S 53°33′W	2 Extensive disturbance	0 None	1 Intermediate	3	3 Some facilities, including lifesaving	2 Clean and safe for bathing	2 Extensive, used for recreation	7	Recreation: Ideal for recreation, no major conservation issues
6. Cabo Polonio, Uruguay 34°16′S 53°46′W	4 Well developed, little disturbance	2 Oyster-catchers nesting	1 Intermediate	7	1 Limited access	1 Clean but unsafe for bathing in some areas	1 Intermediate	3	Conservation: Wilderness beach in a national park, limited recreation, no ORVs
7. Playa Mansa, Punta del Este, Uruguay 34°58′S 54°57′W	2 Extensive disturbance	0 None	0 Sparse	2	5 Good facilities, including lifesaving	3 Clean and safe for bathing	1 Intermediate	9	Recreation: Accreting urban beach, ideal for recreation, no conservation issues
8. Aguada, Uruguay 34°38′S 54°09′W	1 Severely disturbed	0 None	1 Sparse	2	3 Good access, some amenities	2 Mostly safe and clean	2 Extensive beach	7	Recreation: Ideal for recreation, no conservation issues
9. Santa Teresa, Uruguay 33°59′S 53°31′W	3 Disturbed but largely intact	2 Nesting site for birds	1 Intermediate	6	4 Good facilities, including lifesaving	3 Clean and safe for bathing	2 Wide backshore	9	Mixed use: Recreation – fishing, walking, swimming; some conservation issues needed; ORVs not allowed
10. Portezuelo, Uruguay 34°54′S 55°03′	2 Extensive disturbance	0 None	1 Intermediate	3	4 Good facilities, including lifesaving	2 Fairly clean and safe for bathing	2 Wide backshore	8	Recreation: Ideal for recreation, no major conservation issues
11. Mon Repos Beach, Qld Australia 24°47′S 150°26′E	4 Well managed foredune; conservation park with rangers.	3 Significant loggerhead turtle nesting site	1 Intermediate	8	4 Good access and parking; controlled beach access	3 Low hazards, clean beach	1 Moderate backshore and length	8	Conservation: High value conservation, but also used for limited recreation with seasonal closures
12. Surfers Paradise, Qld, Australia	3	0 None	1 Sparse, beach worms; daily beach raking	4	5 Full infrastructure	2 Moderately hazardous but	2 Moderate	9	Recreation: Fully managed; very popular tourist and recreation beach

28°00′S 153°26′E	Managed foredune; fully developed hind dune area					good safety resources			
13. Bondi Beach, Sydney, Australia 33°53′S 151°17′E	0 Non-existent, fully developed	0 None	0 Impoverished; daily beach raking	0	5 Full infrastructure	2 Moderately hazardous but good safety resources	2 Wide beach, very popular tourist & recreation	9	Recreation: Fully managed for intensive recreation
14. Seven Mile Beach, NSW, Australia 34°50′S 150°45′E	5 Pristine, regressive dune, forest and swamp	2 Three threatened mammal and bird species	2 Dissipative *Donax* clams and beach worms	9	2 Access, parking and basic amenities only	1 Signage only	2 Wide backshore	5	Conservation: National Park, no ORV's; primarily conservation, but low impact recreation permitted
15. Long Beach, South Australia 37°07′S 139°47′E	4 Pristine, semiarid shrubs	2 Orange-bellied parrot nesting	1 Intermediate, *Donax* clams	7	3 Access and parking only	2 Signage only	2 Wide beach, parking allowed on beach	7	Mixed use: Vehicles allowed on beach
16. The Coorong, South Australia 36°01′S 139°28′E	5 Pristine, unstable in locations, semiarid vegetation	2 Orange-bellied parrot nesting	2 Dissipative with rich fauna including, abundant clams	9	1 Limited to none	0 Hazardous	2 Very long, wide beach	3	Conservation: Part national park, controlled ORV use, seasonal closures
17. Seal Bay, South Australia 35°59′S 137°19′E	3 Small well managed dune, used by seals	3 Australian fur seals	1 Intermediate	7	2 Controlled access	1 Hazardous surf	1 Intermediate	4	Conservation: Fully managed and controlled to protect seal colony; guided tours only
18. Cavancha, Chile 20°13′S 70°08′W	0 Backshore with urban development	0 None	0 Low diversity and abundance	0	5 Excellent infrastructure	3 Low hazards and fairly pollution free clean	1 Intermediate	9	Recreation: No conservation issues
19. Reñaca, Chile 32°58′S 71°32′W	0 Backshore with urban development	0 None	0 Low diversity and abundance	0	5 Excellent infrastructure	2 Moderate hazards and fairly clean	1 Intermediate	8	Recreation: No conservation issues
20. Cobquecura, Chile 36°07′S 72°48′W	3 Disturbed but largely intact	2 Rocky points nearby harbour breeding seals	1 Intermediate	6	3 Good access, some facilities	2 Moderate hazards and clean	2 Intermediate	7	Mixed use: Used for bathing, walking, fishing; high public concern for seal conservation
21. Calfuco, Chile 39°47′ 73°23′	4 Well developed, little disturbance	0 None	2 Intermediate species richness but high abundances	6	2 Reasonable access	1 Moderate hazards and clean	1 Intermediate	4	Mixed use: Beach primarily used for surf fishing, sun bathing and walking
22. Colún, Chile 39°52′S 73°26′W	5 Dune system pristine and extensive	2 Nesting areas for birds	1 Intermediate	8	0 No infrastructure, difficult access	2 Moderate hazards and clean	2 Wide extent	4	Mixed use: Site protected by The Nature Conservancy; native forests back the beach
23. Maule, Chile 35°32′S 71°42′W Armoured sites	0 No significant dunes where there is armouring	0 None	1 Intermediate	1	2 Variable, often limited infrastructure	0 Hazardous at high tide due to armouring	0 Restricted by armouring	2	Mixed use: Limited use, not really suitable for recreation or conservation.

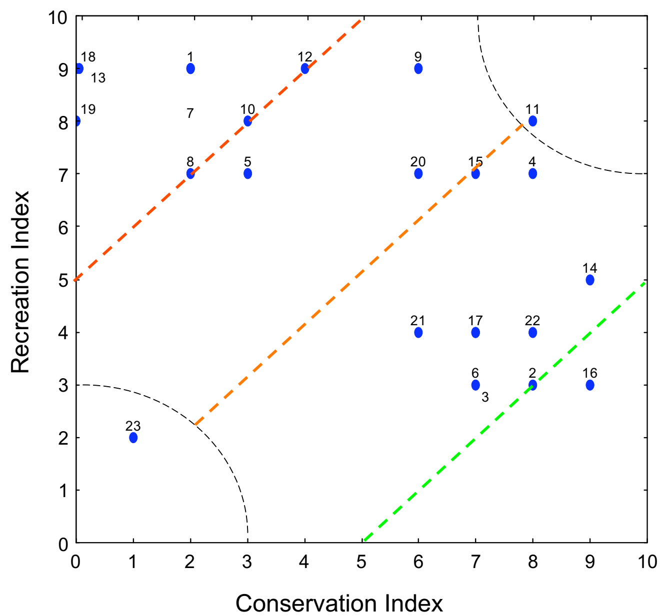

Fig. 4. The location of each beach listed in Table 3 relative to its CI and RI scores.

Website: http://www.derm.qld.gov.au/parks/mon-repos/index.html

Description: Mon Repos is located on the tropical Queensland coast and is a tide-modified reflective-low tide terrace beach type located in a mesotidal regime. It is a significant turtle nesting site for loggerhead turtles (*Caretta caretta*) in addition to flatback and green turtles. It is managed for both turtle nesting and recreation. The entire 1.5 km long beach and foredune is part of the Mon Repos Conservation Park, which is managed by the state. The park runs tours as well as a turtle research and monitoring program. Access and parking is controlled and during the November to March turtle nesting season the public can only enter the beach at night to view the turtles as part of a paid guided tour. The tours run every night, with nesting occurring between November and January and hatchlings emerging between January and March. The public is permitted to use the beach for recreation during the day and at night outside of the nesting season and lifeguards patrol the beach during the summer holiday periods. Boardwalks are used to cross the foredune and no one is permitted on the foredune at any time. In addition to the turtles, the park protects a mangrove-lined creek and rainforest shrub behind the foredune and the beach is also bordered by intertidal basalt rock fields and tidal pools.

Example 4. Bondi Beach, Sydney, Australia (Table 3 number 13)

Theme/strategy: Intense recreation

Relevant principles/guidelines: 1, 7, 8

Website: http://www.waverley.nsw.gov.au/things_to_do/beaches_and_the_coast/bondi_beach

Description: Located 8 km east of Sydney's CBD, Bondi Beach has been a popular recreational site since the 1880's and is today the most popular beach in Australia. The 900 m shoreline curves between two prominent sandstone headlands and faces southeast into the dominant southerly swell, resulting in energetic wave conditions and a persistent rip-dominated intermediate beach. The beach was backed by active parabolic dunes that extended up to 2 km inland. During the early 20th century the dunes were levelled and developed for parkland and housing, and a continuous seawall was built at the back of the beach, leaving an unusually wide (~100 m) dry beach for recreation. The wall is backed by a boardwalk, parking, large amenities, two surf clubs (founded in 1904 and 1907), and parkland, then the Bondi commercial and residential area. Today the beach is managed exclusively for recreation. Lifeguards patrol the beach 365 days a year and the beach is raked every morning. The beach is used by residents and tourists year round, with a distinct peak during the warmer summer months. During the 2000 Sydney Olympics the Olympic beach volleyball stadium was built on the beach and subsequently removed. A shark net is located off the beach, and two tidal rock pools were constructed on the rock platforms at either end of the beach in the 1920's. From the 1880's until 1990, raw sewage was discharged off the northern headland, resulting in regular water pollution and beach closure. The construction of deep ocean sewer outfalls in 1991 dramatically reduced the pollution and the beach is now rarely closed. Bondi, like all popular Sydney beaches, is monitored daily for water quality, with the public alerted to any pollution. The southern headland is an Intertidal Protected Area, which prevents the removal of any marine organisms; however, recreational fishing is allowed on the beach and headlands.

Example 5. Maule, South Chile (Table 3 number 23)

Theme/strategy: Mixed use/limited use due to impacts of armouring

Relevant principles/guidelines: 1, 2, 3, 4, 6, 10

Description: This area of coastline includes sections that are armoured with seawalls and revetments. The sand beach macrofauna of sites located in front of seawalls and revetments, which experienced strong swash action during high tides due to the effects of these structures, had low species richness and population abundances as compared with the macrofauna found on unarmoured sites (Jaramillo, 2011). Dune plants had also disappeared in front of the interacting armouring structures. Moreover, almost no intertidal width was left for human recreation, such as walking or sun bathing. During the earthquake of 27 February 2010 in south central Chile, the width of the intertidal zone of sandy beaches located at the Arauco Peninsula (ca. 36°S) and nearby areas increased due to continental uplift of 2–2.5 m. This resulted in unexpected interactions with armouring including i) creation of new upper intertidal habitat seaward of seawalls, followed by rapid colonization of previously absent mobile upper and mid shore crustacean fauna, ii) loss of lower shore invertebrate species because of the uplift of rocky substrate into the lower intertidal (Jaramillo et al., 2012), and iii) recolonization of the uplifted substrate by native and exotic terrestrial plants. Thus there was some improvement in beach condition in armoured areas that had been affected by uplift. These results demonstrate that in narrow or wide beaches with armouring, particularly where armouring interacts with waves during high tides, these coastal habitats are effectively lost for both conservation and recreation purposes.

6. Discussion

The coastal zone is under growing threats from accelerated population growth as well as becoming increasingly stressed by the impacts of climate change. Simultaneously, our study and understanding of coastal processes, ecosystems and management have developed enormously over the past few decades. This twin growth in both coastal issues and understanding, provides today's coastal managers with potential access to a substantial range of approaches to managing their section of coast. Yet, while there is a vast and expanding literature of coastal zone geography, engineering, ecology, management, climate impacts, and related issues, it will be beyond most coastal managers to even attempt to keep up with this proliferation of information or to obtain extensive scientific data on their beaches, particularly in developing countries (Hastings et al., 2012).

We have therefore aimed here to cut through this overwhelming load of information to identify the key issues associated with beach management in order to determine the most suitable management approach, develop a set of simple indices and provide a succinct set of management principles that can easily be followed, even with limited resources. The indices are aimed at the beach level, particularly management of the subaerial beach and backing foredune. They are concerned with how the beach is perceived and utilized, and in particular whether the use is primarily for conservation or recreation. We believe our approach will cover the full spectrum of recreation and conservation options, with only special cases of other extractive uses likely to lie outside the range of scenarios we have provided.

Table 3 and the case studies illustrate the application of the CI and RI indices and the ten guiding principles as well as presenting examples of some effective management of conservation, mixed use and recreational beaches. We have shown that beaches can be grouped in five categories based on the combination of the two indices, and have given a detailed example from each category: (i) primarily conservation – Sunday's River beach, (ii) mixed use – Barra del Chuy, (iii) high potential for both uses, thus high conflict potential, and need for careful management – Mon Repos beach, (iv) intense recreation – Bondi beach, and (v) low potential for conservation or recreation due to disturbance and hence limited use – Maule beach. Only heavily impacted beaches will fall in the latter category and the spread of points in Fig. 4 shows that most beaches score above 5 on at least one of these indices. Thus most beaches have reasonable potential for recreation or conservation or both, and therefore can be used and need to be managed. Although this has been based on ocean beaches, it should have wide applicability, including to extremely microtidal situations, such as the Mediterranean, but possibly not beaches in estuaries and enclosed lagoons.

It is also possible to gauge the suitability of existing management strategies and implementation in achieving their stated goals. Many beaches throughout the world are under increasing pressure from development and resource use now exacerbated by the impacts of climate change. These simple indices provide a mechanism to identify existing and potential beach usage (recreation through to conservation), which will assist in developing appropriate management strategies. We recognise that, to some extent, use patterns evolve naturally, urban beaches being inevitably directed towards recreation while remote rural beaches trend towards conservation. This natural evolution may, however, result in some mis-matches where high conservation or hazardous beaches are used for recreation, while other potential recreation beaches may be unnecessarily quarantined for conservation. The CI and RI indices will permit both a re-evaluation of existing use, as well as providing a valuable too when planning future coastal use and development.

Both scenario planning and management guidelines will differ according to the nature and extent of human activities, as well as socio-economic and cultural needs of each country/society. For example, in developing countries with a low or very low Human Development Index (HDI), where there could be a lack of alternative employment, subsistence activities should be a priority, requiring resource management/conservation to permit ongoing exploitation. By contrast, commercial activities could be permitted in countries with low/medium HDI, and well planned recreational activities could be conducted in developed and urbanised coasts historically used intensively for recreation, where recreational potential is much higher and unemployment issues should be not significant. A combination of these categories is always possible, and in this scenario variable alongshore and even temporal zoning could be seen as the best strategy for planning and management for multiple beach uses. If feasible, this should incorporate marine reserves and protected areas where pristine conditions, endangered species or exploitation are encountered.

It must always be borne in mind that, in the face of climate change and inevitable sea level rise, most beaches will be retreating and this, coupled with expanding development along most coastlines, will subject them to coastal squeeze (Defeo et al., 2009). Where available space makes it possible, this can be managed by employing setbacks, buffer zones and retreat. Yet many developed shores do not have this space available, and many more cannot afford to sacrifice valuable infrastructure to accommodate beach retreat. In these instances, how the diminishing or degraded beach systems are managed will become increasingly critical, not only for the provision of recreation, but also the future of beach ecosystems. A variety of other disturbances, most being more limited in space and time, will impinge on beaches, so that, other than in the most remote areas, some active management will be necessary. Finally, governance, legislation and implementation are often the major challenges, especially where resources needed to enforce legislation are limited. Involving stakeholders through co-management is desirable, especially where there is severe exploitation for subsistence or seriously conflicting uses.

7. Conclusion

A simple yet robust matrix based on indices for beach conservation and recreation has been presented. The matrix enables beaches to be identified as to their suitability for either purpose as well as mixed usage. Accompanying the indices are ten guiding principles as to their application, together with an indexing of 23 representative beaches, with five beaches presented as more comprehensive case studies. These data show the effectiveness of the matrix in identifying beach usage and Table 3 and the case studies illustrate some of the successful management strategies applied to these beaches.

What is presented in this paper is a starting point for conservation through recreational beach management. It is clear that, given the wide range of beach types and environments, as well as associated socio-economic and cultural values, a myriad of approaches will be required to manage all beach systems. However, using the CI–RI indices and guided by the ten principles presented here, managers should be able to categorise most beaches. This will enable local authorities not only to gauge the best usage, but most importantly to recognise and apply the management strategies required to ensure that the usage is sustainable.

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