REVIEW ARTICLE

BEACHES – MORE THAN JUST SAND AND FUN.

Beaches evoke images of laughing frolicking children, of buckets and spades and sandcastles. Yet while beaches are highly valued by society and are prime locations for recreation, they also underpin many coastal economies around the world.

The multitude of life that exploits this sandy habitat is rarely noticed: in the view of some, beaches are ‘ecological deserts’ in view of the apparent lack of life. Such a view is not that uncommon and was embraced by coastal biologists till around 30 years ago. Among the consequences of this misconception has been that the biological study of sandy beaches has seriously lagged behind that of rocky shores. In addition, biologists working on sandy beaches have tended to view life patterns on sandy shores as modifications of those encountered on hard substrata (Brown and McLachlan, 1990). Since the majority of the global coastline (two thirds, according to Reise, 2000, and three-quarters, according to Bascom, 1980) is sandy in nature, this vast biotic resource merits greater consideration.

Beach and near-shore terminology

A sandy beach is a dynamic interface between sea and land, its boundaries with the adjacent terrestrial and marine environments are not always well defined, with the landward boundary being more defined than the seaward one as pointed out by McLachlan (1983). The same author considers a sandy beach to be part of a dynamic beach/surf ecosystem comprising (i) the sand body from the highest drift line near the dune/beach boundary out to beyond the break point of waves and (ii) the moving water envelope of the surf zone to the outer limit of surf circulation cells where they exist. The surf zone is defined as that part of the beach extending from the waterline to the most seaward point at which waves approaching the coastline commence breaking (Barros *et al*., 2002).

Waves generally break at a distance from the sandy shore, hence wave energy reaches the intertidal zone of a beach as swash (Figure 2). The swash zone is defined as the part of the intertidal zone which is periodically covered by water to response to tidal excursions and wave run-up and is located above the highest tidal level; the position of the swash zone on the beach varies with the tide, shifting landward during high tide and seaward during a low tide (McArdle & McLachlan, 1992). The leading edge of the swash zone is usually marked by a line of foam making it easier to determine where the upwash ends and the backwash begins (Emery & Gale, 1951).

In microtidal conditions (according to the tidal range classification system by Davies, 1964, this corresponds to a tidal range which is smaller than two metres), such as those found in the Mediterranean and Baltic Seas, the beach is considered to start at the foot of dunes and to extend to a water depth of approx. 1m (Jedrzejczak, 2002).

A harsh physical environment

The most fundamental difference between rocky shores and sandy beaches is the nature of the underlying sediment. Unlike rock, sand is a loose, unconsolidated aggregate of sediments – this in itself conditions the physiognomy of life to be found along sandy shorelines. In fact, whilst the fauna on shorelines with non-mobile substrata (such as rocky shores) are conspicuous and mainly macrofaunal (macrofauna = includes organisms larger than 0.5mm or organisms visible with the naked eye), and plants have a firm attachment for root development, the mobile substrata of shorelines like sandy beaches cannot support any persistent, erect vegetational growth, due to their unconsolidated nature. Macrofaunal animals are large enough to be retained by a 1mm sieve; the meiofauna pass through a 1mm sieve but are retained by a 0.05mm mesh, while the microfauna are organisms of less than 0.05mm diameter (Hayward, 1994). While the macrofauna and the meiofauna are ecologically distinct, they are not separated on phylogenetic criteria. In some cases, a single family may have both macrofaunal and meiofaunal representatives and even within a single species, larval or sub-adult forms may be present in the meiofauna. Whilst macrofauna actively burrow in sand, meiofauna do not and simply crawl in between sand grains without disturbing them, whilst microfauna generally live attached on the surface on sand grains. Megafauna, including many wading birds, rodents and even primates (Brown & McLachlan, 1990) are also occasional visitors to sandy beaches to forage.

The lack of suitable firm surfaces on beaches for attachment also results in a relatively small number of epimacrofaunal (epifauna = fauna living on the surface of a sediment) species on beaches. The soft nature of the sediment, however, still favours colonization by biota, especially by infauna (fauna living within a sediment), such as burrowing species or species small enough to live perennially between sand grains (interstitial fauna). Unlike epifaunal species, infaunal and interstitial ones can effectively move in three dimensions.

It follows that the grain size of sediment particles found on a beach is the single most important physical factor, which shapes in turn a cluster of other beach-specific physical factors. In fact, different studies report significant correlations between mean sediment grain size and sand organic content, porosity, and microbial populations. The prevalent grain size on a beach basically depends upon the degree of wave exposure of a particular beach and also on the geomorphological characteristics of the same beach (e.g. type of parent rock).

Yet another fundamental difference between rocky shores and sandy beaches is the degree of dynamicity. In fact, sandy beaches can be best understood in terms of the interaction between just three factors - wave exposure, tide ranges and sediment characteristics, known as beach morphodynamics (Rodil & Lastra, 2004). Few coasts around the world are completely devoid of wave action and it has been estimated that half of the energy budget of the world’s coasts is provided by waves (Inman & Brush, 1973). Beaches, dunes and surf zones are considered to be integral parts of a dynamic cycle in which sand is constantly exchanged (Jedrzejczak, 2002). Brown & McLachlan (1990) state that beaches and dunes form a linked system on many beaches – the ‘littoral active zone’.

The different types of beaches

Beaches can be classified on a scale between two extremes – dissipative and reflective beaches (with a series of intermediate states). Dissipative beaches, which are generally flat (low beach slope) and have fine sand, are characterised by low wave energy (i.e. generally, calm conditions), waves breaking far from the intertidal zone, a wide intertidal zone, long, infrequent swashes, and a high organic matter content. At the other end of the spectrum, reflective beaches, which are steeper and have coarse sand, are characterized by high wave energy (hence, highly exposed conditions), waves breaking abruptly in the intertidal, a narrow intertidal, short, frequent swashes and a low organic matter (Figure 4). Since the 1970’s, a number of different beach morphodynamic state indices/descriptors have been proposed, including the Beach State Index (BSI), the Beach Deposit Index (BDI) and, more recently (by McLachlan & Dorvlo, 2005), the Beach Index (BI).

A number of different beach-related hypothesis have been drawn up over the years. The most widely-cited one is the Autecological Hypothesis, first proposed by Noy-Meir, 1979, and then later refined into the Swash Exclusion Hypothesis. The gist of both hypothesis is that sandy beaches are physically controlled environments where communities are structured by the independent responses of individual species to the physical environment, biological interactions being minimal. Hence, it follows that species richness, individual abundance and biomass are expected to increase from microtidal, reflective conditions to macrotidal, dissipative ones.

Besides the patterns of variation in biotic descriptors (including individual abundance and species richness) over different beach types, some other global patterns have emerged. For example, in concordance with observations in most other habitats, species richness increases from temperate to tropical conditions – however, individual abundance and biomass exhibit the opposite trend, increasing from tropical to temperate conditions. This could be attributed to greater food availability, due to greater productivity provided by more abundant benthic fauna and surf zone phytoplankton (McLachlan, 1990).

Are biological interactions important on a beach?

Some sandy beach researchers contest the minor role accorded to biological interactions on sandy beaches and to the claim that beach macrofaunal species are essentially unspecialized generalists. According to Dugan *et al.* (2004), for example, competitive interactions not only affect the distributions and zonation of intertidal macroinfauna but potentially also community structure, as negative effects accrue over time, such as the increase in exposure to physical processes as swash and wave action that competition for space could lead to. These negative competition-driven effects act in concert with strong physical forces to exclude species from certain beach zones or communities. McLachlan & Dorvlo (2005) claims that, whilst on a global scale physical forces control macrofaunal distributions on sandy beaches, on finer scales and towards dissipative (sheltered) beach states, biological factors may become more important in structuring sandy beach macrobenthic communities.

Faunal adaptations and diversity on a beach

In order to survive in the hostile environment of sandy beaches, faunal organisms exhibit a number of adaptations, including the ability to burrow in the sand, nocturnal activity, a cryptic colouration and the ability to exploit different food sources. Such adaptations are related to maintaining the position on an unstable sediment, to minimizing loss of moisture and adaptation to thermal stress and to a lack of a reliable food source. However, although sandy beaches are harsh environments fitted only for the hardier organisms, they are not poor in food. To the contrary, food materials from a wide area are concentrated there within a narrow band (Gunter, 1979). Food production and the sources of food for animals living along sand beaches are considerably different from those of rocky shores. Since the substratum on sandy beaches is too unstable for colonization by macrophytic plants, the basic food along the beach is microscopic plants, chiefly diatoms, bacteria, various other unicellular algae and detritus (Gunter, 1979). The major feeding mechanisms of sandy beach organisms are suspension feeding on organic material in the water column and deposit feeding on organic detritus on or within the sand.

Most of the food consumed on sandy beaches comes from the sea, in the form of drifting material. McLachlan *et al.* (1981), in fact, state that sandy beach ecosystems normally derive their organic carbon in the form of seagrass and seaweed debris, with little input from the land. Beached phytophytal material (sometimes referred to as ‘wrack’) includes algae (such as the giant kelp species *Macrocystis pyrifera* along Pacific coastlines) and seagrasses (including the genera *Posidonia*, *Zostera* and *Heterozostera*). Figure 6 shows wrack of the seagrass *Posidonia oceanica* along Maltese shores, forming extensive accumulations known as ‘banquettes’ throughout the Mediterranean Sea.

Besides these sources of organic input to sandy beaches, in the intertidal zone, as the waves swash over the sloping beaches, large volumes of water sink into the sand and are filtered as they percolate back to lower levels. This has the effect of transferring large amounts of particulate and dissolved organic matter to the organisms living in the interstices of the sand. In addition, in the subtidal zone, the water pressure at the sediment surface increases as each wave crest passes. This has the effect of forcing water into the sediment, a process known as wave pumping (Figure 7). By this means, considerable amounts of organic matter are transferred to the interstitial community, provided that the sediment particles are not too fine.

Organic material may also reach sandy beaches from the land, as on sandy beaches around river mouths following annual spring high-water periods, or sandy beaches backed by sand dunes, whereby the dune vegetation contributes to the organic content upon decomposition. In addition to the purely natural causes of organic deposition upon beaches, artificial ones, which mainly result from the presence of humans on sandy beaches, may also be regionally important on beaches.

In terms of faunal composition, there is a large disparity between open, oceanic beaches and more sheltered ones (such as those on the fringes of regional seas, as the Mediterranean Sea). In fact, the former are dominated by intertidal species such as polychaetes (e.g. the lugworm *Arenicola marina*) and molluscs (e.g. the bean clam *Donax* spp.), whilst the latter, having a much narrower intertidal zone and a much more extensive supralittoral zone (not inundated and subject mainly to the influence of sea spray), are dominated by insect species, namely beetles (Order: Coleoptera, of which the Family Tenebrionidae – darkling beetles – and the Family Staphylinidae – rove beetles - are the best represented), bees, wasps and ants (Order: Hymenoptera) and true flies (Order: Diptera), and spiders, opilionids and pseudoscorpions (Class: Arachnida). Not surprisingly, some of the arthropod species common on sandy beaches (namely tenebrionids) are also common in arid and semi-arid environments, including deserts.

The crustacean order Amphipoda is common on both types of beaches, decreasing in abundance with increasing distance inland, contrary to insects which are most abundant in the dunes. Some beach macrofaunal genera and/or species have a quasi-global distribution on sandy beaches and are thus useful for inter-beach comparative studies or as indicators of beach state – these include the amphipod *Talitrus saltator*, the isopod *Tylos europaeus* and the tenebrionid genus *Phaleria* spp (Figure 8). The surf zone of beaches worldwide is dominated by crustaceans, namely mysids, isopods, decapods, tanaeids, amphipods and cumaceans (Figure 9). Meiofauna is dominated by far by roundworms (Phylum Nematoda), whilst the phyla Gastrotricha, Rotifera and Tardigrada and the classes Turbellaria, Oligochaeta and Ostracoda also being well represented in the meiofaunal fraction.

Challenges facing sandy beaches

Their very popularity as a recreational amenity can be considered to be a Damocles sword perennially held aloft the preservation of beaches as functional ecological units.

The multitude of direct anthropogenic threats facing sandy beaches include offroading intense human presence (resulting in extensive trampling, changes in beach profile), and habitat manipulation (including removal of beached wrack and dune clearing), whilst indirect threats include coastal constructions (e.g. promenades, groynes, tourist facilities, roads) which may alter the sediment supply to beaches, thus resulting in heightened erosion rates, and climate change-mediated erosion (as a result of rising sea levels). Not surprisingly, 70% of beaches worldwide are witnessing trends of erosion (Bird, 1996).

Whilst the conservation importance of many dune areas has been highlighted, ‘bare-sand’ areas are frequently overlooked, again probably due to the apparent lack of life. Recent research has shed light on the diversity of life inhabiting sand – for example, Weslawski *et al.* (2000) report that, although the macrofauna of sandy beaches is not impressively diverse, it is far from poor, with 200 different macrofaunal species being reported from beaches worldwide. Such a species census is mainly based on studies conducted on tidal oceanic beaches and does not take into consideration ‘dry’ supralittoral macrofaunal species, such as insects. Recent studies are underscoring the conservation importance of so-called ‘pocket beaches’, which are flanked on both sides by headlands and which usually have a limited extent (Figure 11), normally occurring on sedimentary islands, like those of the Maltese archipelago. Diffraction by headlands prevents the occurrence of longshore (shore-parallel) currents and thus, the exchange of sediments and suspended fauna between adjacent pocket beaches. Consequently, pocket beaches can be considered as ‘sediment-tight’ systems, which harbour distinct faunal assemblages. The concept that no beach faunal assemblage is expendable is novel in islands where beaches are valued as a tourist industry asset

Sandy beaches are far more than just places for recreation. They have a complex and important ecology, one that needs greater understanding and greater protection.

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